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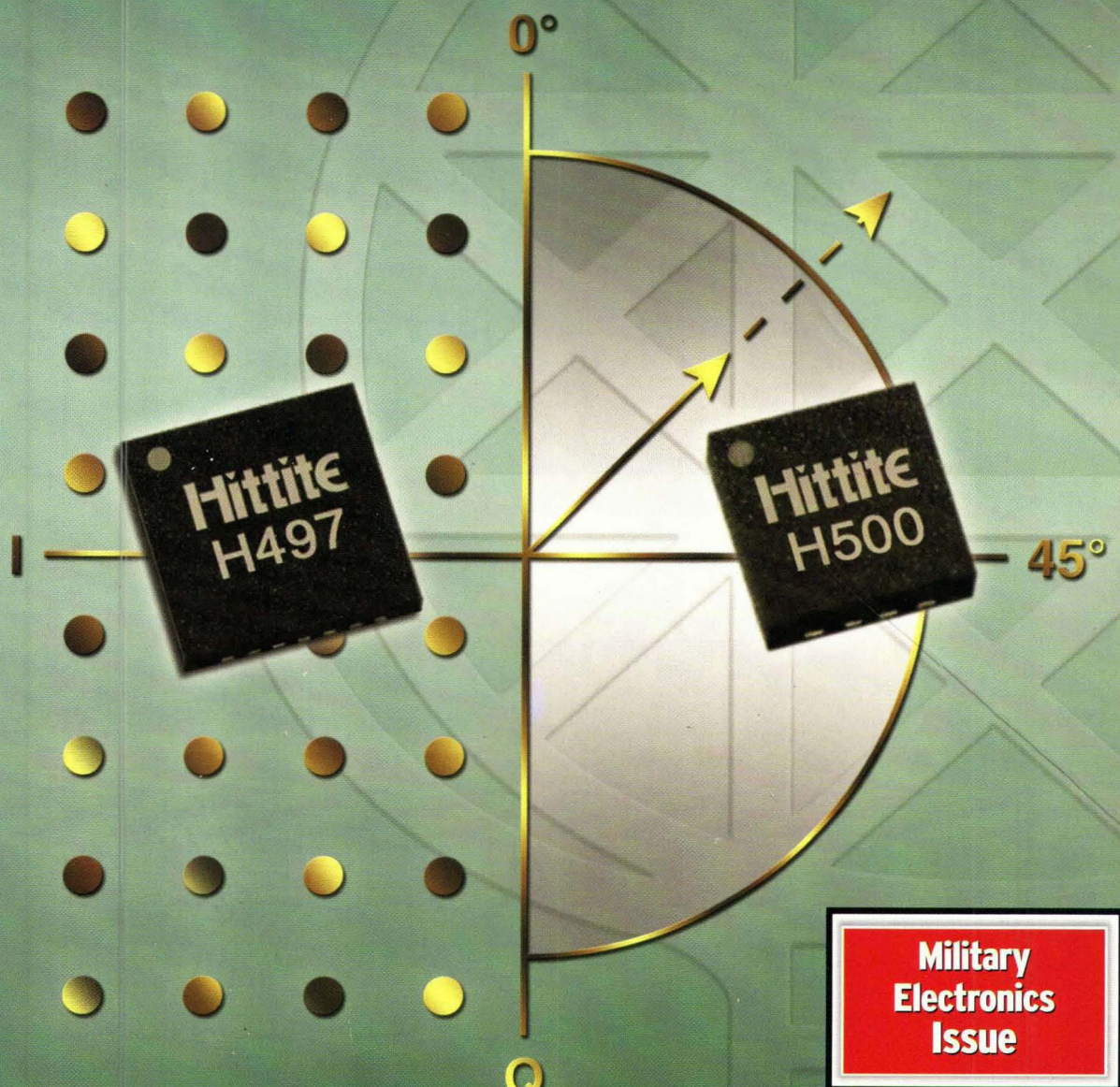
Microwaves & RF

News
ATE system speeds avionics testing

Design Feature
Modulation choices for telemetry transmitters

Product Technology
Palm-sized analyzer surveys 6 GHz

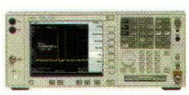
Modulators Direct Linear Gain and Phase



Military Electronics Issue

Every adventure has its essentials

Engineering is no different



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PSG signal generators with integrated vector modulation and PC-based signal generation tools

PNA Series microwave network analyzers, with electronic calibration and vector-corrected mixer techniques

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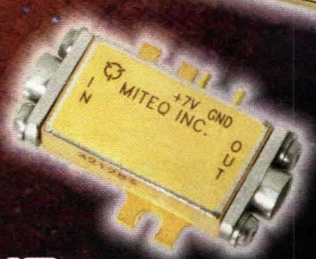

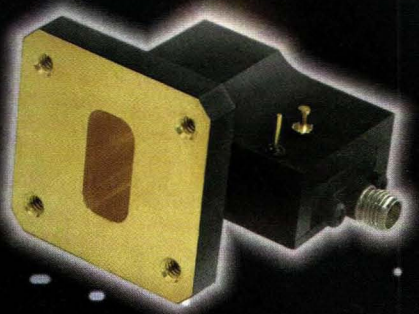

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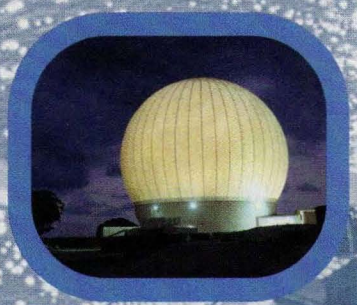
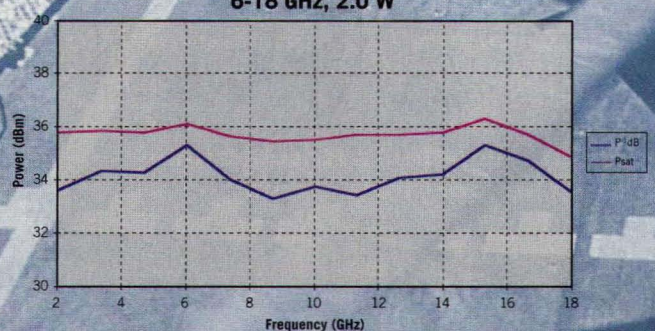


Model dB min	Freq. Range dB min	Gain dB min	Flatness +/–dB	1 dB Comp. pt. dBm min	N/F Max	3rd Order ICP typ	VSWR In/Out Max
LNA's							
JCA12-3001	1.0–2.0	40	1.0	10	**0.8**	20	2.0
JCA24-3002	2.0–4.0	40	1.0	10	**1.0**	20	2.0
JCA48-4001	4.0–8.0	42	1.5	15	**1.0**	25	2.0
JCA812-5001	8.0–12.0	45	1.5	10	**1.5**	20	2.0
JCA1218-5002	12.0–18.0	48	1.5	10	**1.5**	20	2.0
Ultra Low Noise Amplifiers							
JCA45-306	4.5–4.8	40	0.5	10	**0.5**	20	2.0
JCA45-305	4.4–5.1	30	0.5	10	**0.7**	20	2.0
JCA56-309	5.4–5.9	30	0.5	10	**0.7**	20	2.0
JCA78-306	7.25–7.75	30	0.5	10	**0.7**	20	2.0
JCA12-3040	1.2–1.6	30	0.5	10	**0.7**	20	2.0
Broadband Power Amplifiers							
JCA618-4001	**6.0–18.0**	40	1.5	**33**	3.0	40	2.0
JCA218-3002	2.0–18.0	34	2.0	**27**	4.0	33	2.0
JCA218-4002	2.0–18.0	44	2.5	**27**	4.0	32	2.0
JCA218-5002	2.0–18.0	54	2.5	**27**	4.0	32	2.0
JCA218-3001	2.0–18.0	30	2.0	**25**	4.0	30	2.0

Low Phase Noise Amplifiers

Carrier Offset	C, X-Band (-dBc/Hz)	Ku-Band (-dBc/Hz)
100 Hz	**135**	**125**
1.0 kHz	**145**	**142**
10 kHz	**153**	**150**
100 kHz	**158**	**152**

6-18 GHz, 2.0 W



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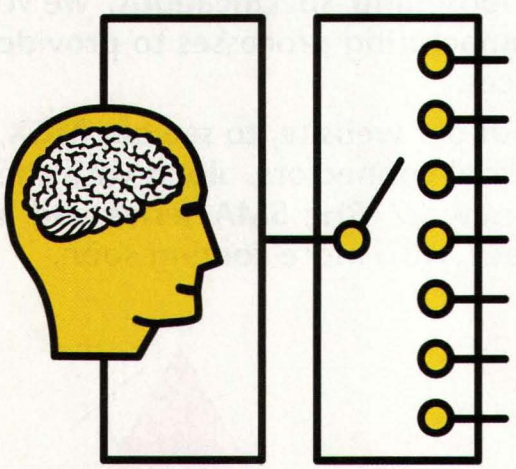

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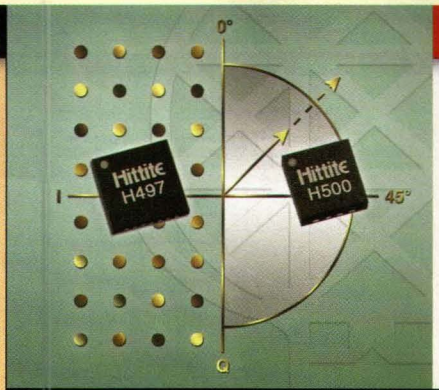


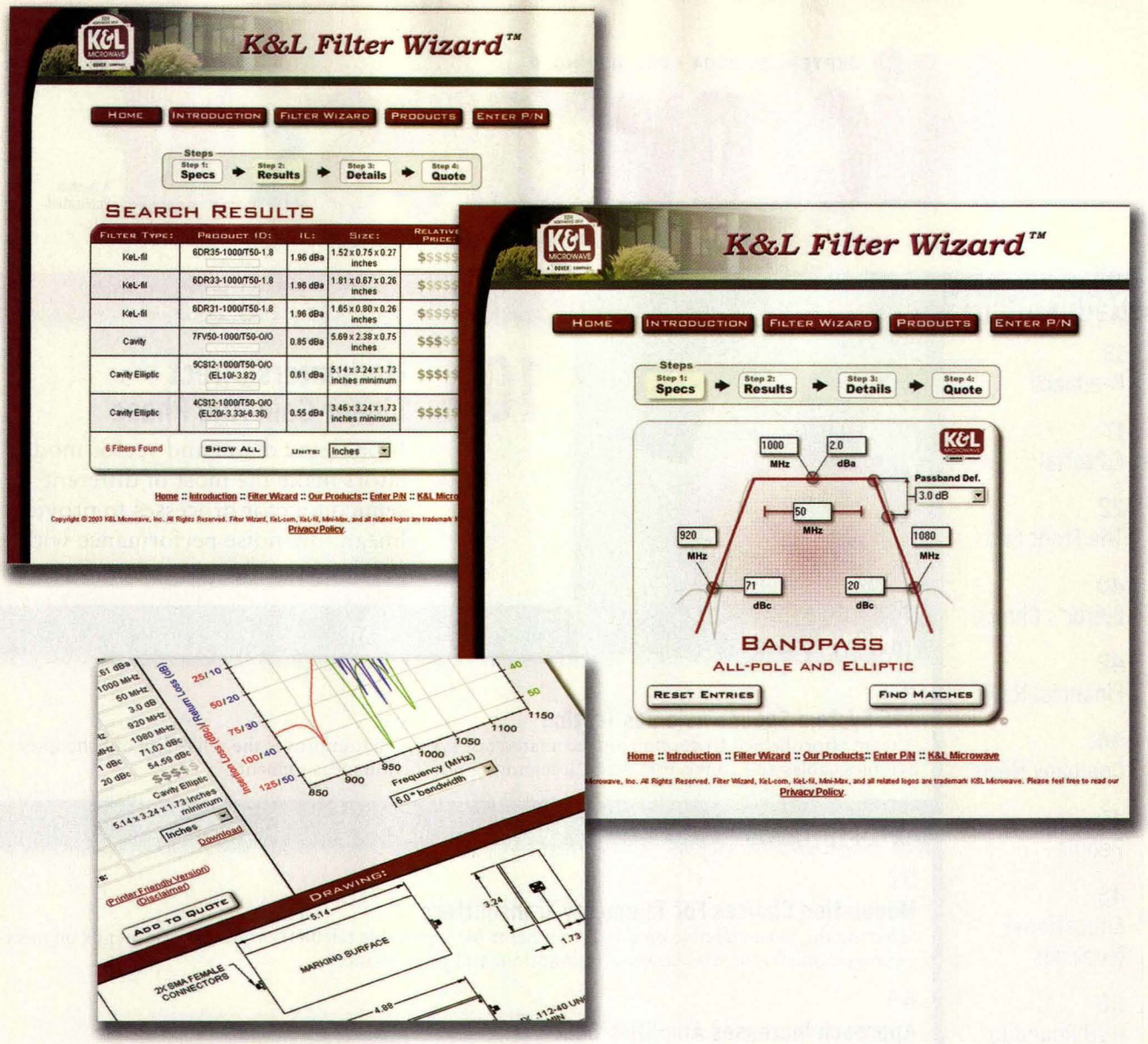
COVER STORY

News

Design

Product Technology

Penton



simplicity...

Designing a communications network, RF Sub-assembly or military system is, in a way, like completing a puzzle. Piece by piece you search for the components that offer the highest quality, state-of-the-art features, competitive pricing and most importantly...compatibility. After all, if they don't work together then the puzzle isn't complete.

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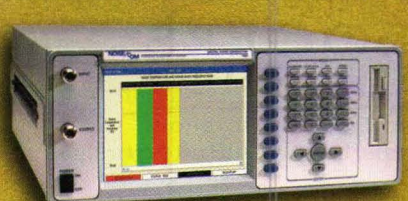

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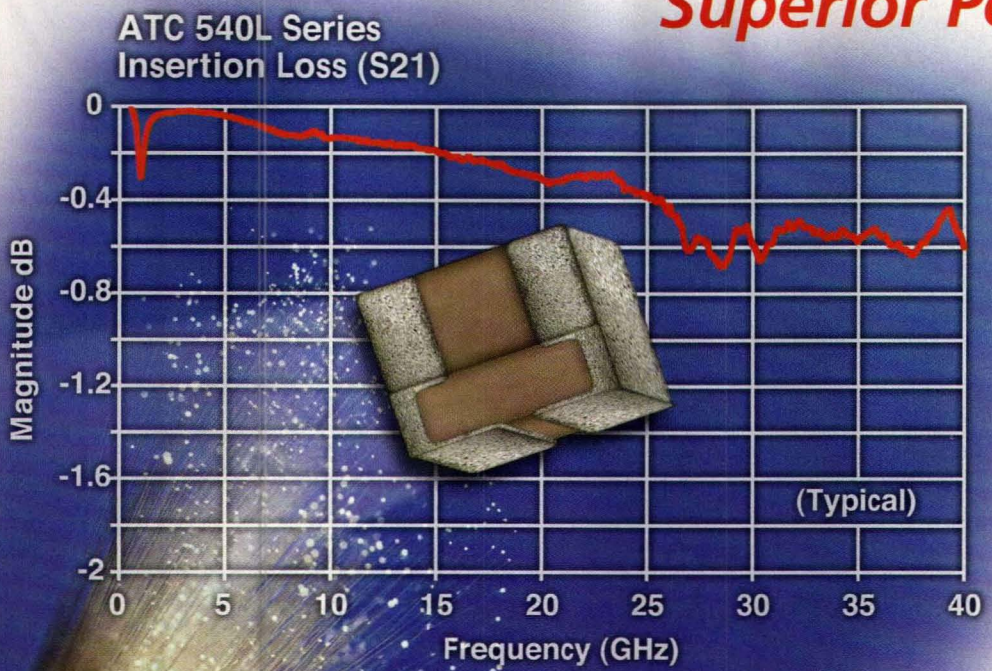

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OPERATING FREQUENCY (MHz)	MODEL NUMBER	GAIN (dB, Min.)	GAIN FLATNESS (±dB, Max.)	VSWR IN/OUT	NOISE FIGURE NF_1 (dB, Max.)	NF_0 (dB, Max.)	NF_2 (dB, Max.)	OUTPUT POWER (dBm, Min.)
0.001 – 500	AU-1534	30	0.5	2.0:1	1.3	1.4	1.5	+8
0.01 – 200	AU-1442	35	0.5	2.0:1	1.2	1.2	1.2	+5
0.01 – 200	AU-1447	56	0.5	2.0:1	1.2	1.2	1.2	+12
0.01 – 250	AU-1559	11	0.5	2.0:1	4.2	4.2	4.2	+16
0.01 – 400	AU-1565	54	0.75	2.0:1	1.2	1.2	1.3	+14
0.01 – 500	AU-1310	30	0.5	2.0:1	1.3	1.4	1.5	+8
0.01 – 1000	AU-1402	18	1.0	2.0:1	6.0	5.0	5.0	+16
0.01 – 1000	AM-1300	27	0.75	2.0:1	1.4	1.6	1.8	+8
0.01 – 1000	AM-1431	35	0.75	2.0:1	1.4	1.6	1.8	+8
0.1 – 2000	AM-1364	9	1.5	2.0:1	6.0	6.0	6.0	+10
1 – 200	AU-1464	35	0.5	2.0:1	1.2	1.2	1.2	+6
1 – 400	AU-1421	24	0.5	2.0:1	2.4	2.4	3.1	+17
1 – 500	AU-2A-0150	30	0.5	2.0:1	1.3	1.4	1.5	+8
1 – 500	AU-3A-0150	44	0.5	2.0:1	1.3	1.4	1.5	+10
1 – 500	AU-4A-0150	60	0.75	2.0:1	1.3	1.4	1.5	+10
1 – 1000	AM-2A-000110	26	0.75	2.0:1	1.4	1.6	1.8	+6
1 – 1000	AM-3A-000110	35	0.75	2.0:1	1.4	1.6	1.8	+8
5 – 200	AUP-1568	26	0.75	2.0:1	5.0	4.5	4.5	+28
5 – 300	AUP-1495	11	0.75	2.0:1	15	9.0	9.0	+28
5 – 300	AUP-1496	23	0.75	2.0:1	8.0	7.0	7.0	+28
5 – 300	AU-1021	24	0.5	2.0:1	2.7	2.8	2.9	+20
5 – 300	AUP-1479	36	1.0	2.0:1	2.5	2.7	2.9	+28
5 – 1000	AM-1475	36	0.75	2.0:1	1.4	1.6	1.8	+15
5 – 2000	AM-1573	18	1.5	2.0:1	4.0	4.0	4.0	+21
5 – 2000	AM-1590	36	2.5	2.0:1	3.8	3.8	3.8	+20
5 – 2000	AM-1591	48	2.5	2.0:1	3.8	3.8	3.8	+20
100 – 1000	AM-1412	35	0.75	2.0:1	1.4	1.6	1.8	+14
100 – 2500	AM-1585	26	2.0	2.0:1	3.6	3.6	3.6	+20
200 – 2000	AM-1569	20	1.5	2.2:1	4.2	4.3	4.6	+14
1000 – 2000	AM-1477	37	1.0	2.0:1	1.8	2.1	2.4	+15

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Figure Correction

▶▶IN FIGURE 1c of the Cover Story of our July 2004 issue ("Software Speeds Complex IC Design," p. 92), the lines indicating Ansoft Corp. and Competitor were trasnsposed. The error made it appear that Ansoft was seven times slower than the Competition when, in fact, Ansoft is seven times faster. The corrected version of this figure appears on the Web at www.mwrf.com/Files/30/8499/Figure_01.gif. We apologize to Ansoft Corp., the authors (Deepak Ramaswamy, Mark Reichelt, Mary Tolkias, and Z.Y. Daniel Wu), and the readers for the error.

The Editors of Microwaves & RF

S-Parameters

▶▶I'VE BEEN READING Joseph F. White's article on S parameters in the July 2004 issue of *Microwaves & RF* ("Applying S-Parameters To Amplifier Design," p. 92; see part 3 of this article series on p. 65—Ed.). His examples with the 2N6679A are very helpful and I'd like to do some additional study of the transistor itself, especially since the article will be in eight parts and may refer to the 2N6679A again, but I can't find a data sheet for it. The Motorola and ON semiconductor websites don't seem to recognize the part and my old data book library, which I had thought was pretty complete, has nothing.

There is a Russian webpage with some description, so I know that it's an SOT100 package and the ratings are roughly 30 V and 75 mA if my Russian is correct. Anyway, could you please help me out?

J. Arthur Smith
Dynatronix, Inc.

Joseph F. White comments: Thank you for your interest in my article.

The Motorola 2N6679A is now probably an obsolete transistor. I selected it from the library contained in the Genesys circuit simulator library because I needed a set of S parameters to demonstrate amplifier design.

The table on p. 77 of the July issue, "S-parameter file for the 2N6679A bipolar transistor from Motorola," might be of some help to you.

Given your interest in the entire series of articles (from which I do beleive that one will be able to become an amplifier designer), I think that you would benefit from obtaining my book, High Frequency Techniques, An Introduction to RF and Microwave Engineering *(John Wiley & Sons, Hoboken, NJ, 2004, www.wiley.com), from which this series is excerpted.*

In any event, thanks again for your interest. I wish you well in your engineering endeavors.

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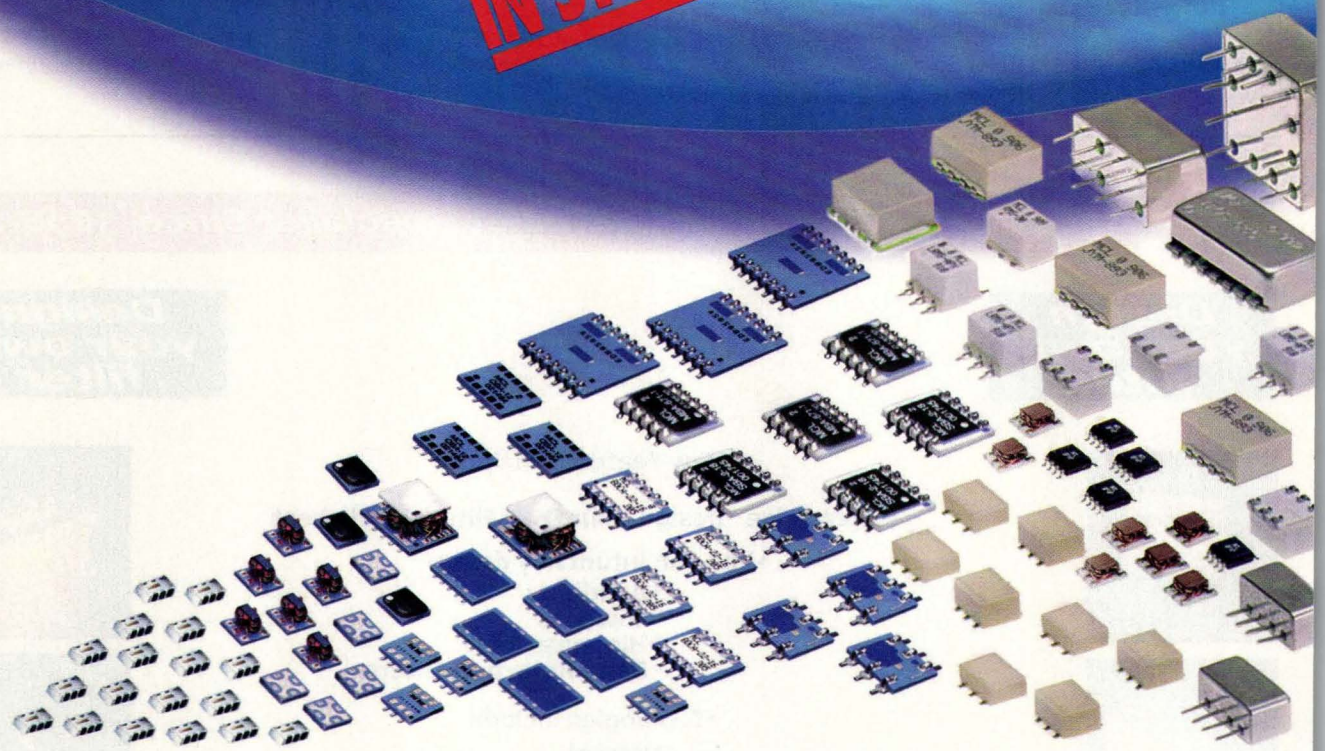

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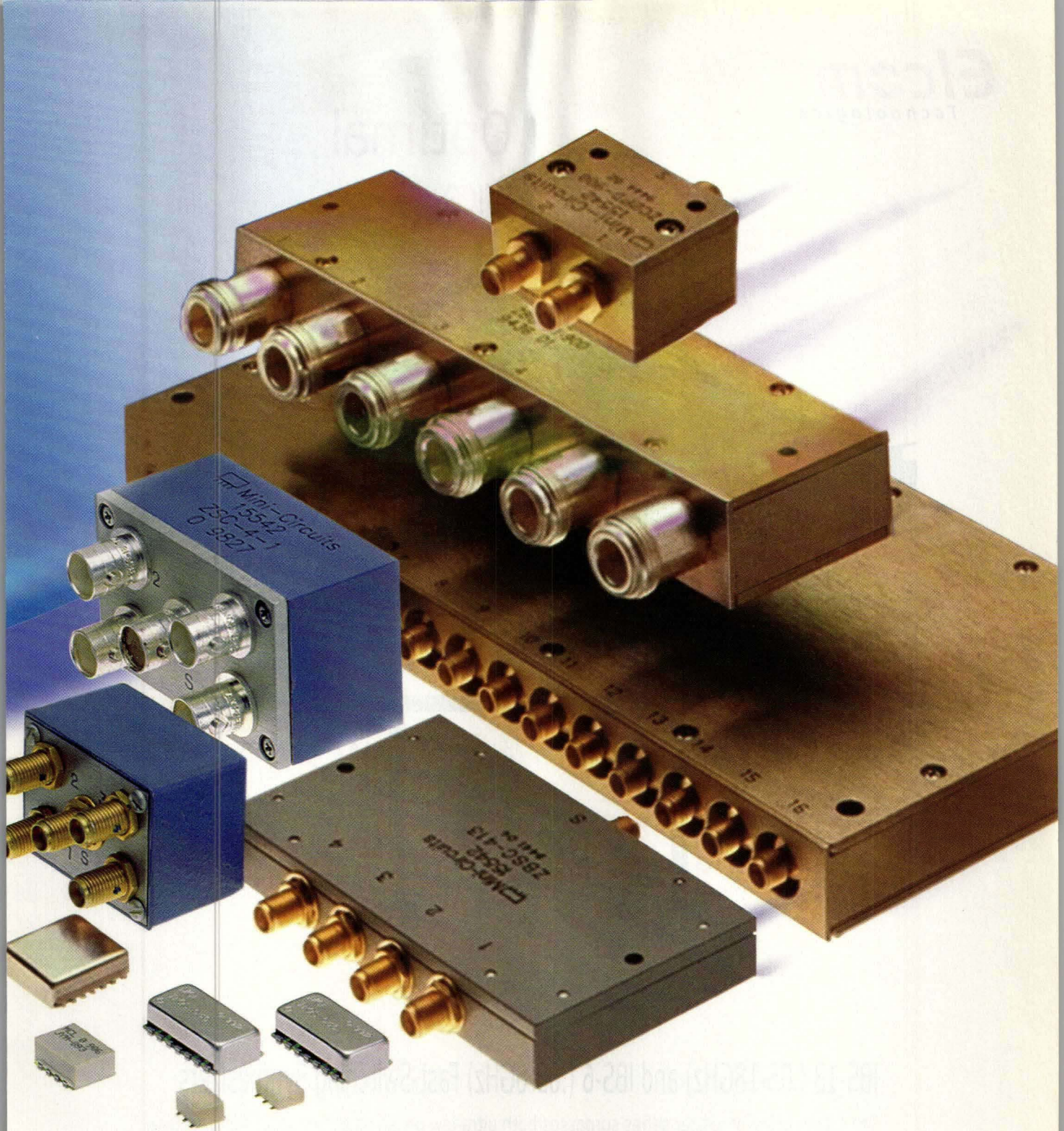

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20KHz	-150	-137	-129	-116
100KHz	-153	-140	-130	-120
Noise Floor	-153	-153	-153	-150

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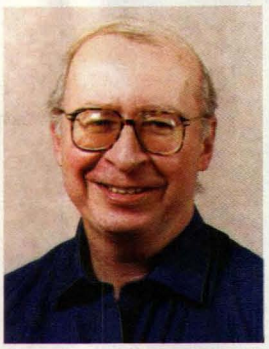
Planning For Future Combat Systems



Military electronics is a comprehensive "umbrella" term that covers a wide range of systems.

CASUALTIES ARE an inevitable part of any military conflict, as Americans have constantly been reminded by this country's involvement in Iraq. Effective military electronic systems can help to minimize those casualties, however, by providing what at times may be just a split-second edge, but enough of an advantage to save a life.

Military electronics is, of course, a comprehensive "umbrella" term that covers a wide range of systems, from the traditional ground-based, airborne, and shipboard radar systems that are the roots of this industry to advanced communications and surveillance equipment and electronic-countermeasures (ECM) systems that provide early detection and response mechanisms to an enemy's presence. The armed forces have long supported the development of such systems as separate entities creating, for example, communications systems that would not always network effectively between branches of the military. More recently, however, the different services have recognized the need for teamwork in the form of joint development programs.

One of the more ambitious of these joint development programs is the joint US Army/DARPA program known as Future Combat Systems (FCS) that would be networked across all military services. The basic concept of the FCS is to provide a soldier with access to a total of 18 different systems, including advanced manned vehicles and unmanned robotic reconnaissance vehicles/sensors, so that the soldier's own senses are effective extended into hostile regions without putting that soldier into harm's way. Simply put, the program intends to wage future battles with robots rather than humans. Obviously, the program's advanced systems will heavily leverage proven RF/microwave technologies for remote control and communications within the network.

DARPA is current managing the FCS Concept and Technology Development phase of the program. Once the program enters into the System Development and Demonstration phase, the US Army Program Executive Officer for Ground Combat Systems will take responsibility for systems integration, production, fielding, and sustaining the systems.

The program represents a true practical application of electronics technology to the military in that it should increase the mobility and tactical capability of the individual soldier while fulfilling the "prime objection" of keeping casualties to a minimum. Although the cost of the project was originally estimated at about $92 billion, a reassessment of system needs has added about 25 percent more to this total. Still, the loss of a robot or unmanned vehicle will always be insignificant compared to the loss of a single human life.

Jack Browne

Publisher/Editor

Microwaves & RF
A Penton Publication

Publisher/Editor Jack Browne, (201) 845-2405 • jbrowne@penton.com
Technology Editor Nancy K. Friedrich, (201) 845-2428 • nfriedrich@penton.com
Managing Editor John Curley, (201) 845-2415 • jcurley@penton.com
Special Projects Editor Alan ("Pete") Conrad
Editorial Assistant Dawn Prior • dprior@penton.com
Contributing Editors Andrew Laundrie, Allen Podell

MANUFACTURING GROUP
Group Production Director Mike McCabe
Customer Service Representative
Dorothy Sowa, (201) 845-2453, fax: (201) 845-2494
Production Coordinator Judy Osborn, (201) 845-2445
Digital Production Staff Louis Vacca, Pat Boselli

ART DEPARTMENT
Art Director Patrick Prince • pprince@penton.com
Group Design Manager Anthony Vitolo • tvitolo@penton.com
Senior Artist James M. Miller
Staff Artists Linda Gravell, Michael Descul
Graphics Coordinator Damian Mendez

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EDITORIAL OFFICE
Penton Media, Inc., 45 Eisenhower Dr., Fifth floor, Paramus, NJ 07652
Phone: (201) 845-2446, fax: (201) 845-2493

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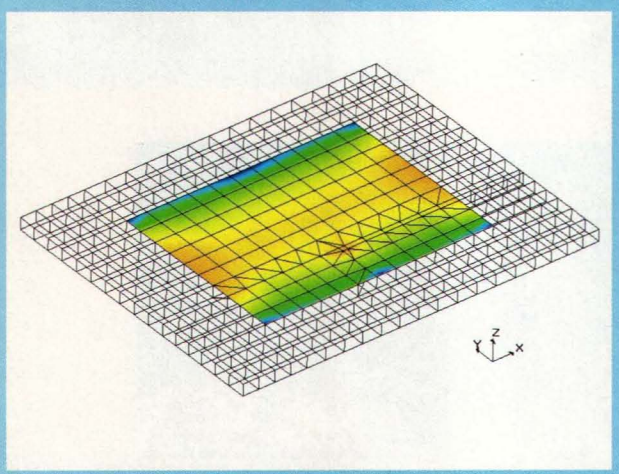
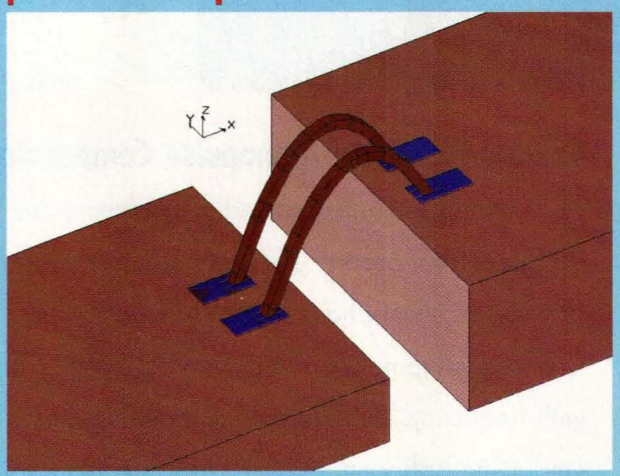
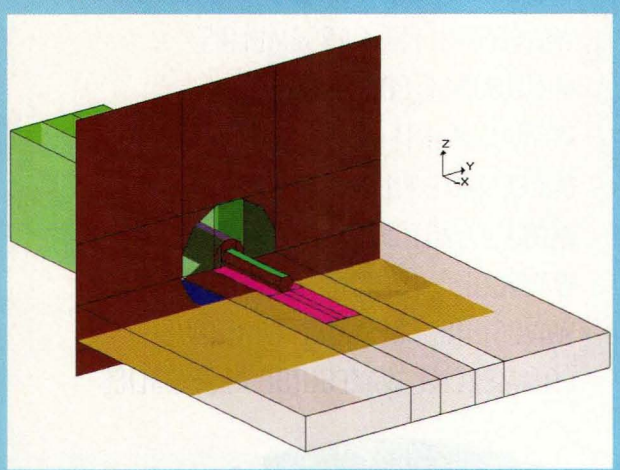


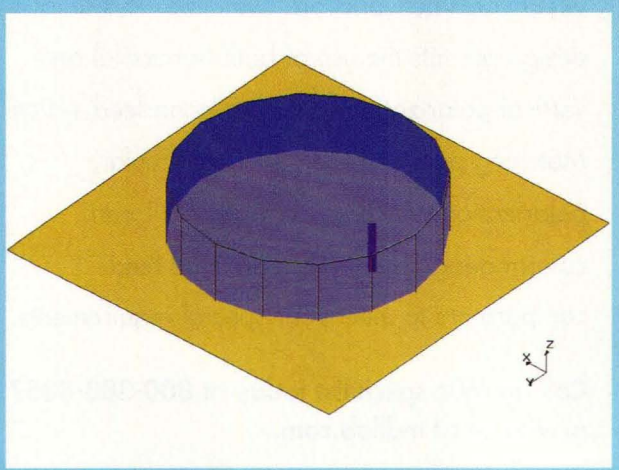
A patch antenna with finite size substrate



Wire bonds in inhomogeneous dielectrics



A coaxial to microstrip transition



A dielectric antenna

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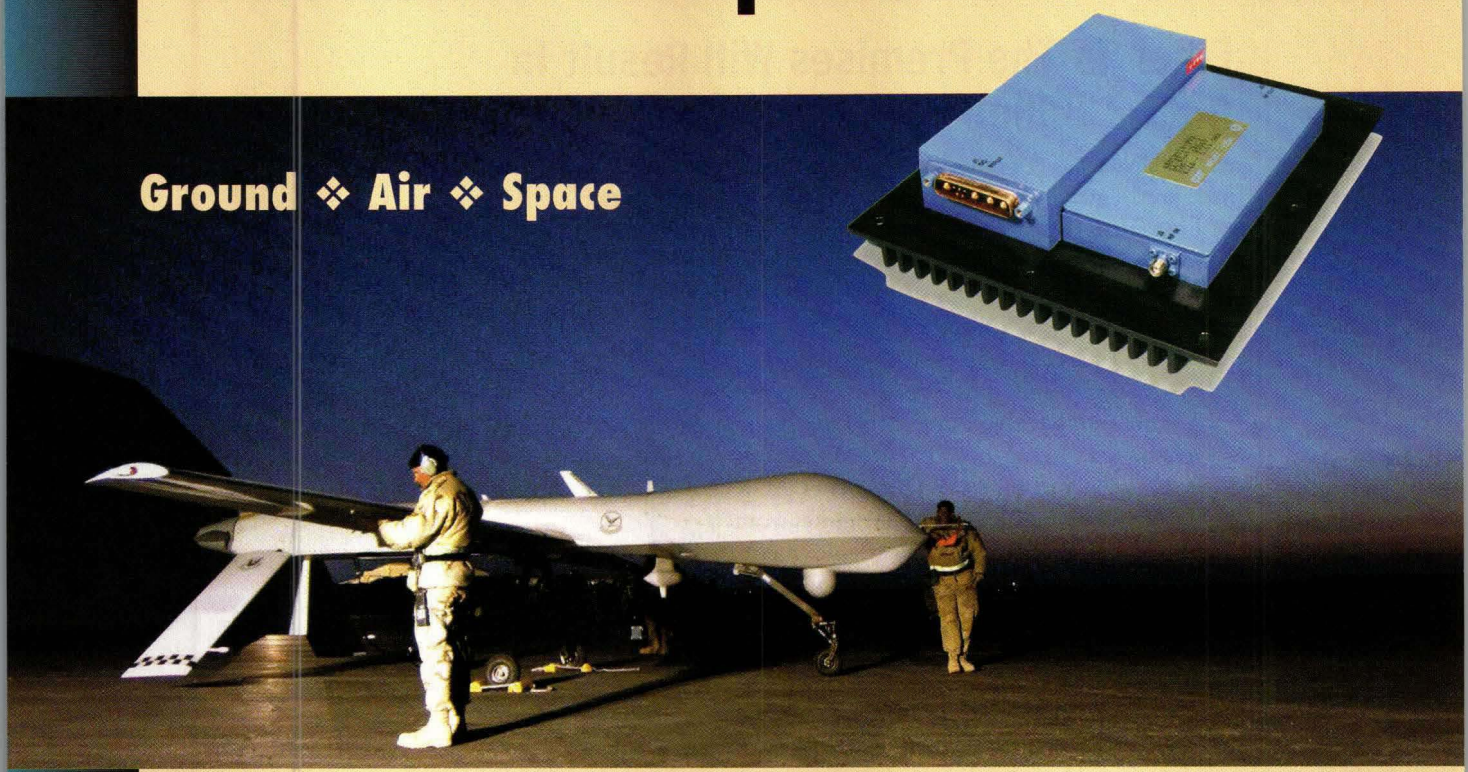

The DoD's Roadmap forecasts the inventory of UAVs to quadruple by the year 2010. Capabilities of UAVs require CDL (common data link)-compatible formats for LOS (line-of-site) and BLOS (beyond-line-of-site) communication. CTT, Inc. has developed a family of GaAs-based solid-state amplifier products and subassemblies designed to accommodate these requirements.

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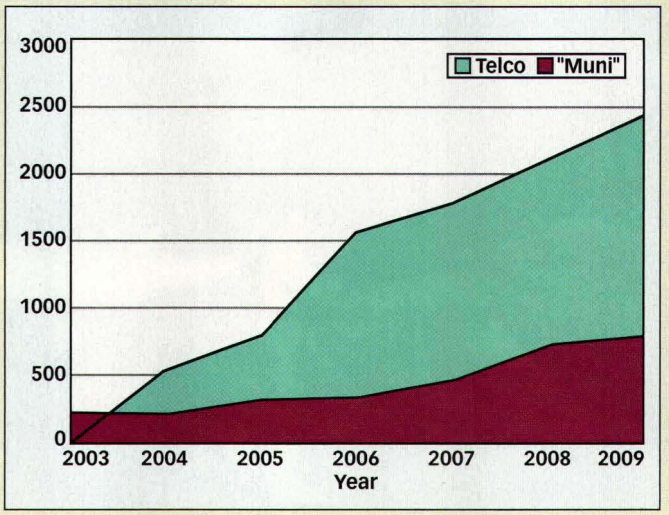
the front end

News items from the communications arena.

Fiber To The Premises Will Result In A $3.2 Billion US Market By 2009

PROVIDENCE, RI—For more than 15 years, fiber-to-the-home (FTTP) deployments have been punctuated by various trials but have never gained traction, until now. In its report entitled *Fiber To The Premises in the United States: The Promise of Universal Broadband Access*, KMI Research forecasts that the total FTTP market for equipment, cable, and apparatus will reach $3.2 billion in 2009. This represents a 54-percent compound annual growth rate (CAGR) for the forecast period.



The amount of cabled-fiber demand used in FTTP and fiber in the loop (FITL) applications in the US will contribute to a 19 percent CAGR for the total US single-mode cable market from 2003 to 2009. FITL-related fiber deployments in 2003 were less than 10 percent of total US single-mode cabled-fiber demand but will account for more than 40 percent in 2009.

In 2003, there was a fledgling fiber to the home, or FTTP, market underway, consisting of approximately 100 different projects—the majority of which were undertaken by municipalities, utility companies, real-estate developers, and other "non-telco" organizations. In 2003, the telcos contributed only 3 percent of the FTTP market for cable and equipment. But with the ramp-up in KMI's forecast, the telcos' deployments will grow much faster than the non-telcos' deployments. Telcos will represent 70 percent of this market in 2009 **(see figure)**.

Wi-Fi Growth Is Being Driven By Broadband Adoption

OYSTER BAY, NY—ABI Research's *Wi-Fi Quarterly Service* shows solid second-quarter growth across the bundle of wireless networking techniques collectively known as Wi-Fi.

According to Phil Solis, senior analyst at ABI Research, this quarter-to-quarter market growth is being driven by different factors in the consumer/SOHO space and in the enterprise. In the former, he says, "Broadband adoption, and its accompanying purchases of access points and adapters, have been boosting consumer spending. And there's still plenty of room for more."

Wi-Fi adoption has been slower in the enterprise sector. Over the past few years, prices for consumer equipment have been falling faster than those for enterprise-grade systems, and the SOHO and consumer spend has outpaced that of enterprises by a good margin.

But a bigger factor preventing greater Wi-Fi adoption in organizations has, says Solis, been security—or the lack of it. Now, however, 802.11i—the protocol intended to ensure Wi-Fi networks' security—has been ratified, giving organizations a much greater level of comfort with the technology.

"With the security issue out of the way," Solis observes, "we should see enterprise adoption continue to grow. It won't be dramatic, but it will be solid."

According to ABI Research's market intelligence, the top three vendors of Wi-Fi solutions in the retail and SOHO segment are Linksys, D-Link, and Netgear, while in the enterprise sector, the top trio consists of Cisco, Symbol Technologies, and Proxim.

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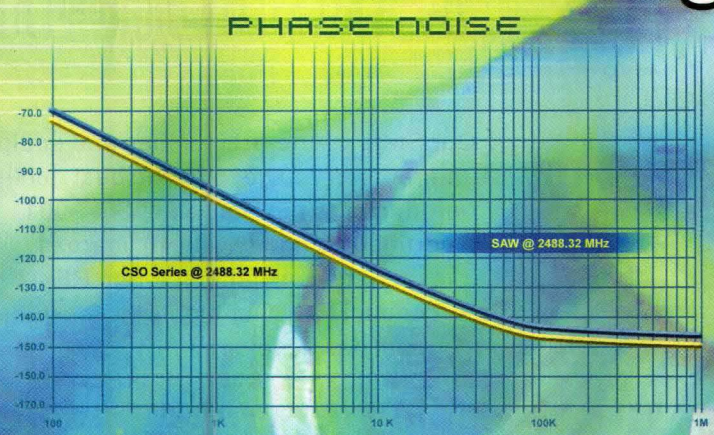

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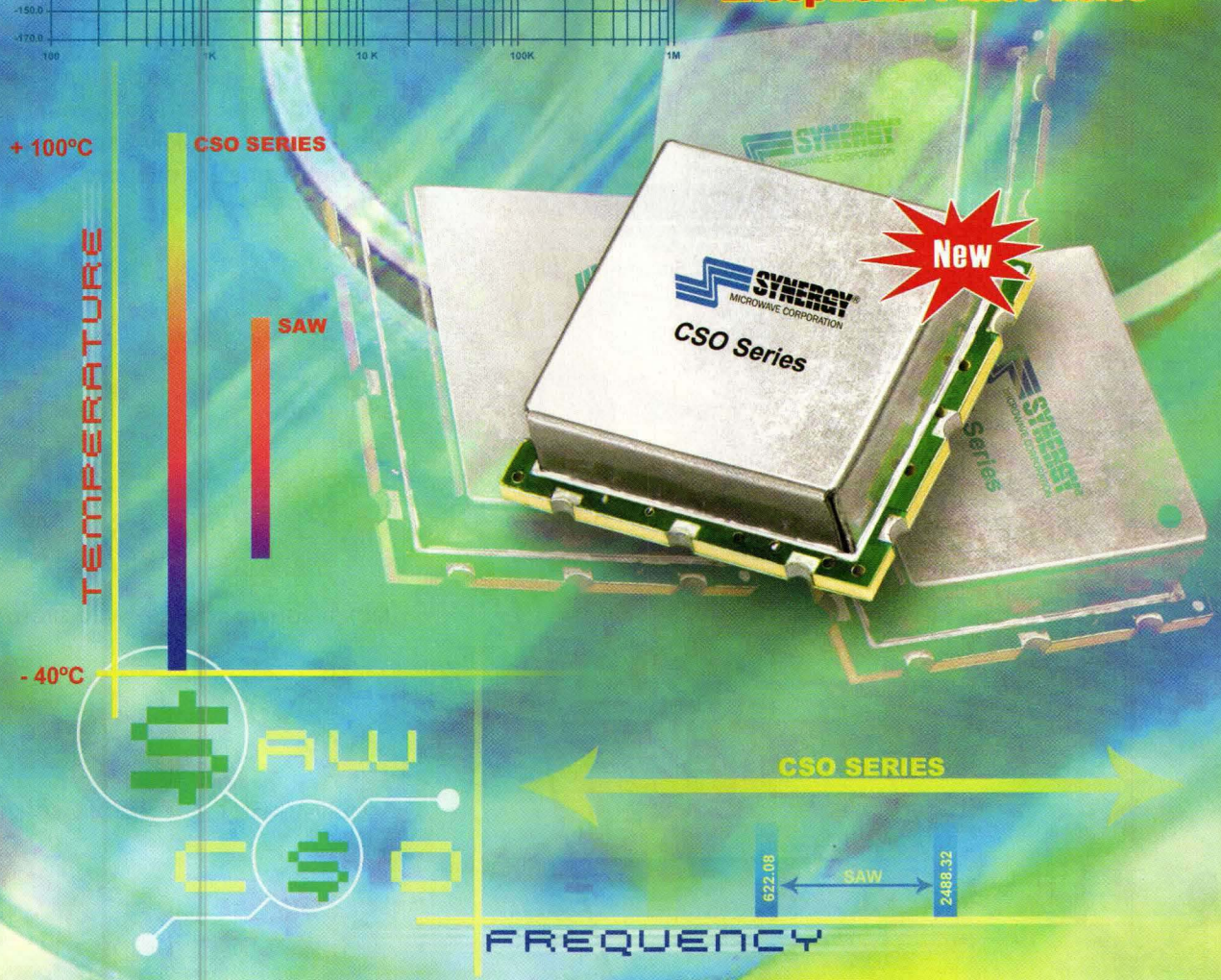

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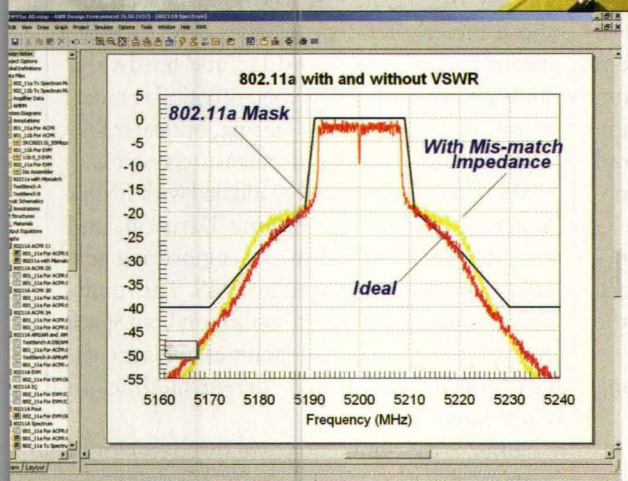

Getting a clear upfront view of VSWR effects can eliminate a lot of unexpected system turbulence downstream. Traditional software assumes ideally matched interconnections between models. But the real world involves impedance mismatches, phase noise, and RF nonlinearities that can capsize your project or turn your timetable upside down. Only Visual System Simulator™ has the patent-pending RF models to show the impact of VSWR on BER. And cascaded budget analysis can monitor the entire RF link and map out potential drop-offs before your system hits the rocks. Download a 30-day demo from mwoffice.com or call 310-726-3000 for details.

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Eagleware Becomes A Member Of The EDA Consortium

NORCROSS, GA—Eagleware, a supplier of high-frequency design software for the RF and microwave industry, announced that it has become a member of the EDA (Electronic Design Automation) Consortium, an EDA-specific industry group whose mission is "to promote the health of the EDA industry and to increase awareness of the crucial role EDA plays in today's global economy." Through its active participation, Eagleware joins with other Consortium members to identify and address issues common to Consortium members and the customer-communities they serve.

The EDA Consortium sponsors the flagship events of the EDA industry, including the Design Automation Conference (DAC) in the US and the Design Automation and Test in Europe (DATE). In addition, the Consortium promotes awareness of the EDA industry and its concerns through various communication channels such as press releases, sponsored panel discussions, and its website. The EDA Consortium also sponsors the annual Design Achievement Awards to recognize exceptional successful designs and the Phil Kaufman Award to honor individuals who have enhanced the productivity of design engineers.

To learn more about the EDA Consortium, visit www.edac.org.

The US Will Drive Global Cable VoIP Markets This Year

BOSTON, MA—According to a report from the Yankee Group, *Activity Heats Up in the Global Cable VoIP Market*, hosted voice providers such as Vonage and US-based MSOs are responsible for most of the current market growth, but global cable operators are beginning to follow suit.

"Starting in 1997, some US MSOs began to familiarize themselves with telephony deployment and marketing using legacy circuit-switched solutions," states Lindsay Schroth, Broadband Access Technologies senior analyst. "Although margins on this business have been low for some operators, voice remains a crucial element of their bundled strategy."

"After many years of testing, the VoIP technology is finally available and ready for prime time," continues Schroth. "The US market, which represents almost all the cable VoIP market today, also will drive global MSOs to move forward."

During the past year, Cablevision launched VoIP services to its entire high-speed data footprint, giant Time Warner Cable announced plans to make the service available to its entire footprint in 2004, and hosted providers such as Vonage gained traction in the consumer market.

"After many years of testing, the VoIP technology is finally available and ready for prime time."

EMS Technologies Purchases Key Assets Of Multitech Corp.

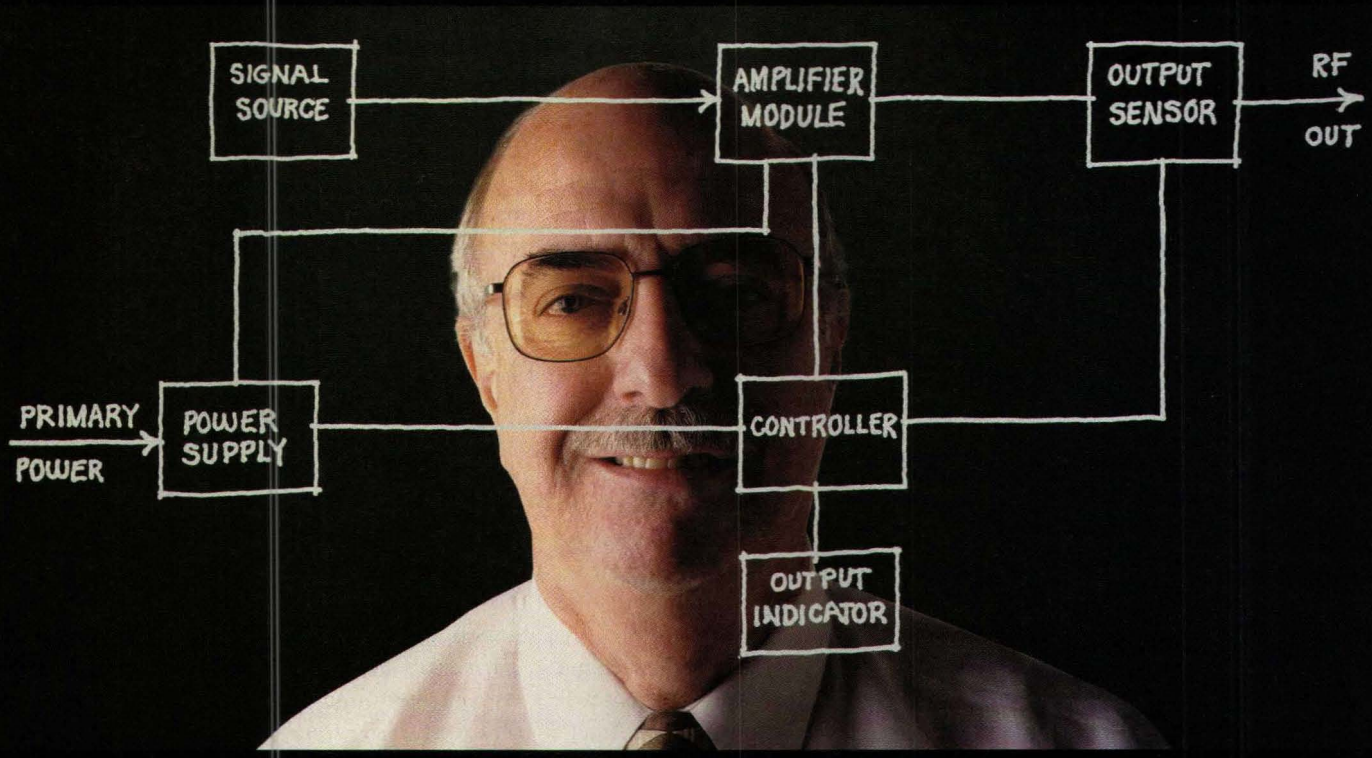
ATLANTA, GA—EMS Technologies, Inc. announced that it has purchased key assets of Multitech Corp. of Clearwater, FL for an undisclosed amount. consideration was principally cash for substantially all of the assets and specified liabilities of Multitech. The assets purchased are those directly related to Multitech's defense electronics business, and include hardware, software, and intellectual property critical to radar, communication, remote sensing, optical tracking, and electronic countermeasure systems.

Multitech's assets will be aligned with EMS's Space & Technology/Atlanta Division, and key Multitech leadership and engineering personnel are now employed by EMS. The resulting operation is expected to operate in both Space & Technology's current facilities in Norcross, GA, and in Multitech's current facilities in Clearwater, FL.

Prior to the transaction, Multitech employed approximately 20 engineers and technicians, all focused upon designing, developing, and manufacturing the highest quality positioning subsystems for antennas and optical and laser instruments for use in terrestrial, naval, and airborne applications.

Jay Grove, senior vice president and general manager of EMS's Space & Technology/Atlanta Division, comments, "By acquiring the Multitech assets, we are adding expertise, capabilities, and key customer relationships to our Defense & Electronic Systems business. The transformation to network-centric, on-the-move warfare has increased the demand for the highest precision positioning capabilities, and Multitech had significant experience and very capable products. As we extend from microwave/millimeter-wave components and antennas to provide complete RF and optical subsystems for our prime defense customers, the capabilities we have acquired from Multitech will add significant value."

SHEP'S VISION.



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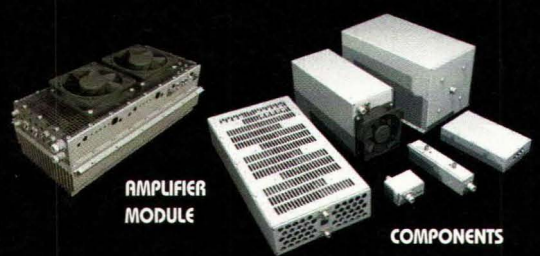

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New Standard Is Helping To Secure Wi-Fi's Continued Growth

AUSTIN, TX—The IEEE has recently approved the 802.11i standard to be used to improve the security of all other 802.11 standards. IMS Research identifies this as one of the main drivers behind the growth of wireless home networks, and forecasts that by 2009, approximately 82 percent of home networks will have some wireless element, and about 57 percent of all home networks will be exclusively wireless.

"By 2009, about 57 percent of all home networks will be exclusively wireless."

"One element that has held back the adoption of wireless home networks has been the concern over security," states Jack Mayo, market analyst at IMS Research. "The 802.11i standard incorporates an Advanced Encryption Standard which provides a higher level of encryption than previous wireless standards, helping to calm consumers' fears, and furthering Wi-Fi's growth."

According to a recent study, wireless home networks in Asia-Pacific and EMEA regions will still not match the installed base in the Americas by 2009, although they are likely to experience stronger growth. This is due to a larger percentage of homes in the Americas with multiple PCs, as well as American consumers having the expendable income necessary for the establishment of a home network. IMS Research forecasts that by 2009, the Americas will account for 41 percent of the worldwide wireless market, Asia Pacific for 32 percent, and EMEA for 27 percent.

While conducting research for the second edition of the study, *The Worldwide Market for Home Networks and Residential Gateways*, IMS Research questioned equipment manufacturers and trade associations concerning topics such as Wi-Fi security. The report provides detailed analyses of the home network market, with forecasts for the number of installations and consumer broadband connections, by type and by region.

Kudos

GREENSBORO, NC—RF Micro Devices, Inc., a provider of proprietary RF integrated circuits (RF ICs) for wireless-communications applications, announced that it has set an industry record as the first wireless semiconductor company to ship 1 billion power amplifiers (PAs) for cellular phones.

EL SEGUNDO, CA—Applied Wave Research, Inc., a provider of high-frequency electric-design-automation (EDA) tools, announced that Analog Office design suite, a solution for next-generation analog and RF integrated-circuit (RF IC) design, has been selected for the 2004 LSI of the Year Award. The product won in the Design Environment/Development Tools category against 150 other nominations. Sponsored by Semiconductor Industry News and Reed Exhibitions Japan, the awards were announced at the annual Embedded System Expo & Conference (ESEC) in Tokyo on July 7.

WARREN, NJ—ANADIGICS, Inc., a supplier of wireless and broadband solutions, received its 43rd patent. The company has been awarded 14 new patents in the areas of power-amplifier (PA) technology, RF circuit design, and electronics manufacturing technology.

BRADFORD, PA—KOA Speer Electronics, Inc. announced that it has been awarded a first-year *Partners in Performance* award by Celestica for its contribution to the company.

Celestica's *Partners in Performance* awards are given annually to the company's suppliers, in recognition of their support of Celestica's supply-chain management objectives and dedication to customer service.

PALO ALTO, CA—Agilent Technologies, Inc. has been awarded the 2004 Market Leadership Award by Frost & Sullivan in recognition of the company's success and leadership in the worldwide VXI market. Agilent was selected for achieving excellence in the areas of market share, revenue growth rates, profitability, and market and technology innovation.

MEDWAY, MA—On July 8, NARTE presented its National Service Award to Art Wall for his contributions to the telecommunications industry. During Art Wall's career at the Federal Communications Commission (FCC) he has been instrumental in development of numerous programs. Among these achievements is the Mutual Recognition Agreements (MRA) with the European Union (EU), APAC, and South America. He has helped craft these agreements in benefit of US test laboratories and manufacturers. Art Wall was also a primary developer of the Telecommunications Certified Body (TCB) program, which privatized the telecommunication terminal and some of the radio certification procedures. This program helped streamline the application process for industry. MRF

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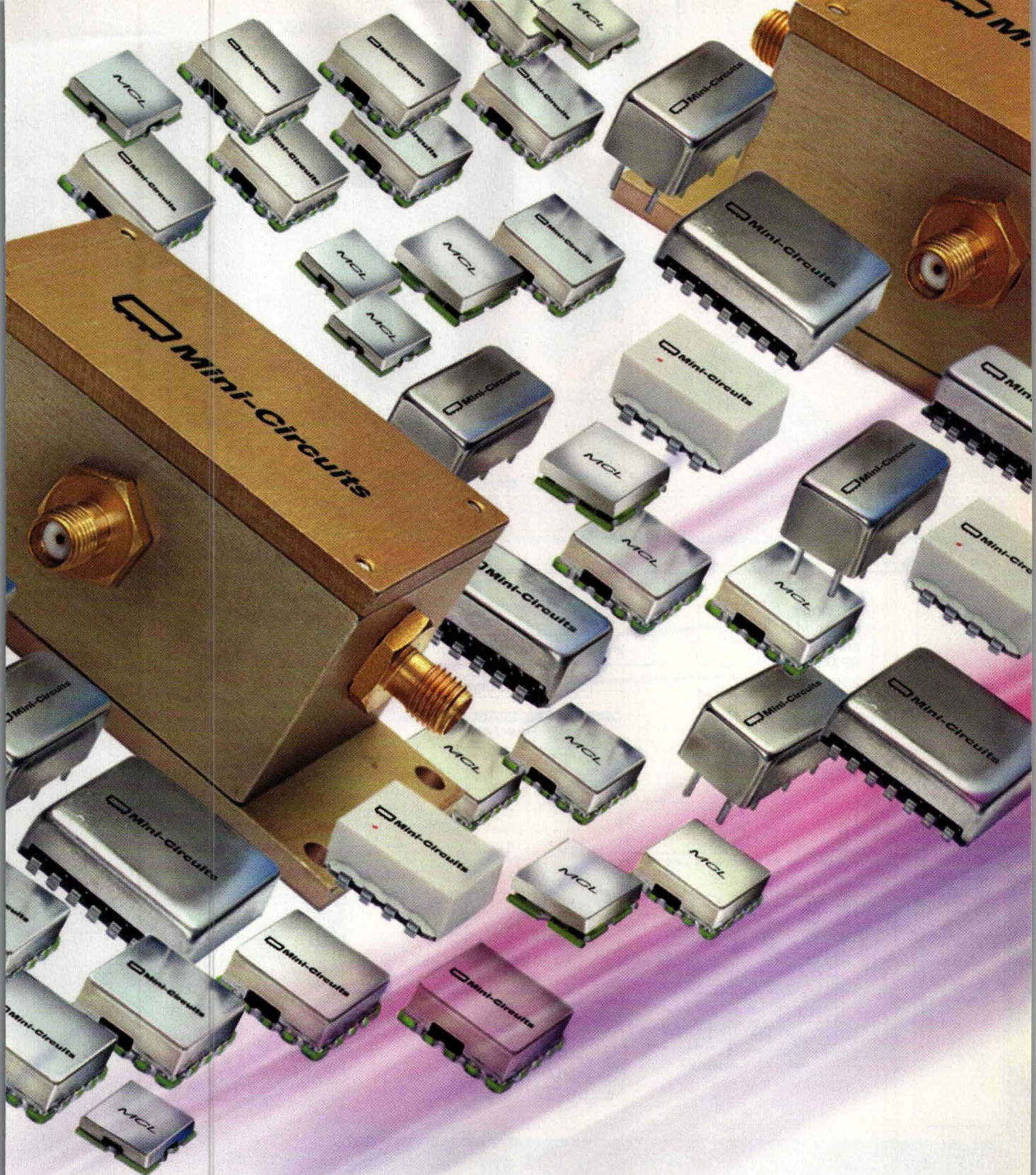

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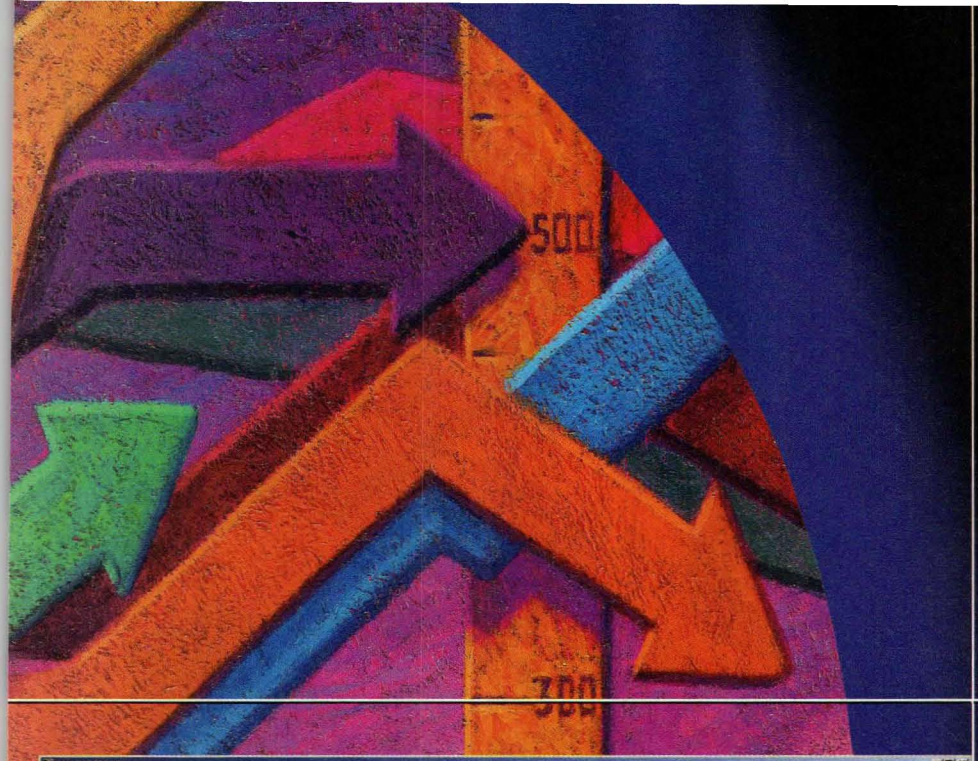

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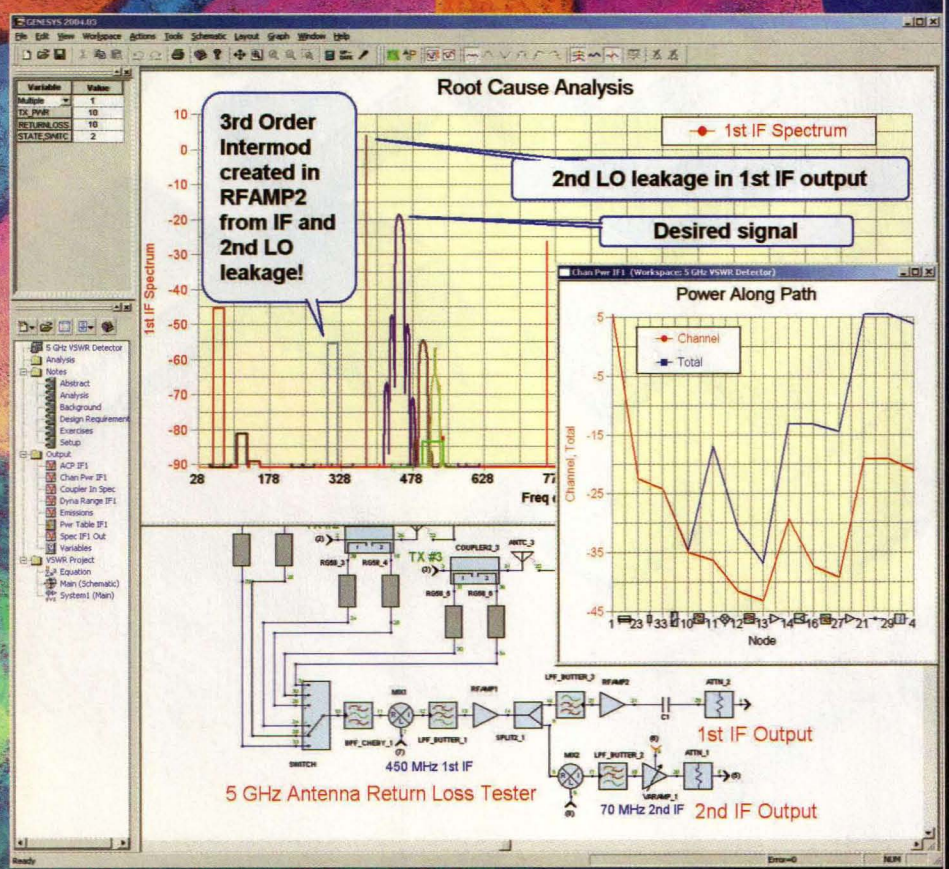

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NEWS

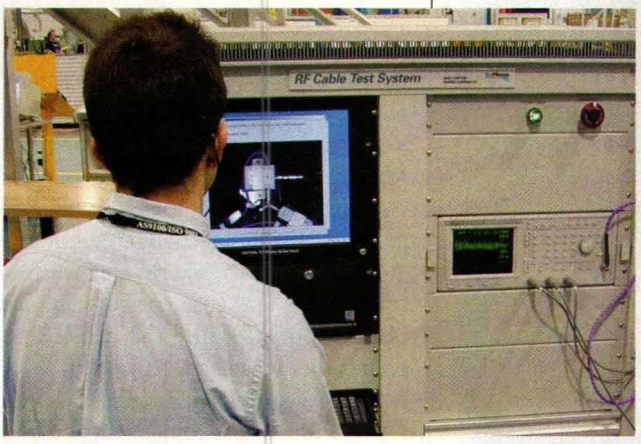
ATE System Speeds Avionics Testing

A team effort helped to develop an automated test system that improves the reliability of helicopter avionics cables and connectors while accelerating production measurements.

Complex avionics and microwave instrumentation systems serve critical roles aboard Boeing Army Rotorcraft Systems' CH-47 and MH-47 Chinooks, MV-22 and CV-22 Osprey tiltrotor aircraft, and RAH-66 Comanche armed reconnaissance helicopters. The company's Ridley Park, PA facility produces completed fuselages for these aircraft destined to fly for US forces including Marines, Air Force, and Army units around the globe. In addition to thousands of components, each chip set incorporates scores of coaxial cables for avionics including communications, navigation, and aircraft-protection (AP) systems. These miles of cables and their connectors must provide fail-safe performance, so testing these cable assemblies is particularly critical to ensuring overall system reliability.

Like all other equipment and systems aboard the helicopters, the coaxial cables, their connectors/terminations, and their antennas must be thoroughly tested to assure conformance to applicable specifications for continuity, insertion loss, VSWR, and other reliability and performance parameters. These include—but are not limited to—phase delay and distance-to-fault (when fault diagnostics are required) measurements to point out cable discontinuities. While just one of many thousands of tasks associated with producing a battle-ready aircraft, these testing

JACK BROWNE
Publisher/Editor



1. This automated test system has cut in half the measurement time of helicopter avionics' cables and connectors.

2. Boeing's automated test system performs electrical measurements on miles of avionics' cables and can even track down the distance to a fault.

procedures are traditionally time-consuming and tedious. Should a completed aircraft experience failures associated with the coaxial cables after it has been delivered to a military customer, more expensive troubleshooting is required by engineers and technicians. An optimized measurement system can help weed out any such potential failures in the coaxial cables.

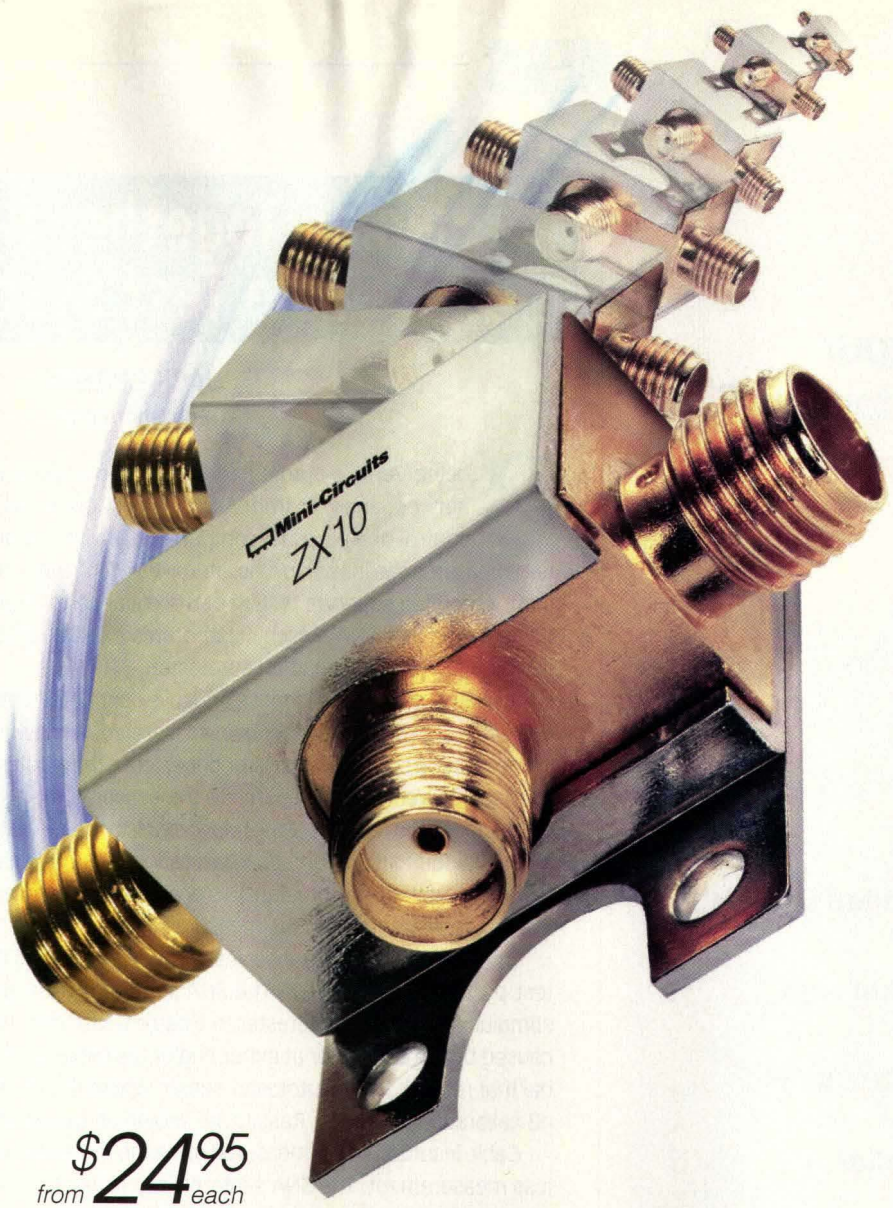
To improve the time-consuming manual test procedures employed by Boeing on these aircraft, Kathy Kocher, a Boeing test engineer for more than 14 years, sought to upgrade the company's existing manual test equipment with automated functional test procedures (FTPs). Kocher and associates at Boeing worked with Joe D'Ignazio at Eastern Instrumentation (Philadelphia, PA), a technical representative for In-Phase Technologies Inc., (Clarksburg, NJ). In-Phase Technologies is well known in the high-frequency industry as a designer and developer of custom ATE systems for analog, digital, RF, microwave, and lightwave measurements.

The efforts of Kocher and her team resulted in a custom automated coaxial-cable test system that eliminated virtually all of the problems associated with the previous manual test procedures. Kocher, who has been involved with coaxial cable testing aboard Boeing helicopters for the past seven years, notes, "The first system was put to work on our Chinooks which are completed here on site. The V-22 fuselages are completed here as well, but after testing they are shipped to another manufacturing facility for final assembly."

Of the company's manual cable testing procedures, Kocher says, "In a good day, a technician could test about five cables aboard a V-22, for example." Even with that relatively low productivity, Kocher admits, "We were usually disappointed with the test results."

Herman Richardson, who represents the Manufacturing Engineer Test System (METS) Group for both the Ospreys and Chinooks, mentions the old way of working: "In the past, by the time our helicopters got to the customer and they started plugging in all the black boxes, there would be failures for many reasons." Richardson, who also serves as a production and instructor pilot for the CH-47 Chinook, is mainly responsible for customer training and instructing military flight crews on the aircrafts' avionics systems after the factory testing and customer acceptance phases. But checking the cables and connectors was never a priority.

Once a completed aircraft has been factory tested, a customer's flight crews bring the systems up to functional status. "When they turn on the electron-



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See our 244 page RF/IF Designer's Guide in EEM (Electronic Engineers Master)

Piecing Together Boeing's Cable Test System

JACK BROWNE
Publisher/Editor

Boeing Vertol's automated coaxial cable test system consists of a scalar network analyzer from Anritsu Co. (Morgan Hill, CA) operating under the control of a personal computer (PC) with custom test software. The system measures the insertion loss and/or VSWR of every coaxial cable within an aircraft. An option supports testing of the distance to a fault for any cable found to be defective. The SNA, which incorporates a dedicated test signal source, is supported by two sensors and an autotester

Typically, an SWR/return-loss bridge is connected between the output of a stable test source and the sensor being calibrated, with two different calibrations performed. First, a short and open are connected to the autotester's test port. This reflects all of the power from the source to the sensor in the autotester. The load is then connected to the test port of the bridge for distance-to-fault measurement calibration.

In addition to the open/short calibration, a through calibration is made to the B sensor through the autotester. This provides a reference power level for insertion-loss measurements, with the measured level serving as a 0-dB reference.

The return loss of a cable under test is measured by inserting it between the autotester's test port and the B sensor. The SNA's internal generator applies RF/microwave stimulus through the autotester to a cable under test. Any impedance mismatch, caused by the connector at either end or the cable itself, produces a reflected signal that returns to the autotester sensor where it is measured in relation to the 0-dB calibration reference. Results are shown on the computer display.

Cable insertion loss is measured using the same test setup as used for the return loss measurement. The SNA's internal signal generator applies an RF/microwave stimulus through the autotester and cable under test to the B sensor connected to the other end of the cable being measured. The insertion loss is analogous to the attenuation of the signal through the actual cable and connectors being tested.

Distance-to-fault measurements are based on frequency-domain reflectometry (FDR). The technique utilizes vector addition of the SNA's internal source output signal with the reflected signals from any faults (impedance mismatches) within the cable under test. This vector addition of the signals creates a ripple pattern at the A sensor of the SNA. The number of ripples is directly proportional to the distance to the mismatch or reflective point on the transmission line.

The software engine that operates the measurement equipment is a LabVIEW based, graphical-user interface (GUI) test executive developed by In-Phase Technologies The test executive provides both text and photographic instructions that prompt the operator in performing system calibrations and measurements. Integrated within the software are GPIB commands that control the SNA, printer and, in the case of a multiple input system, the coaxial switches. Each instrument command is sent over the GPIB bus and the SNA's response data is received and analyzed.

Cable selection is usually made from a directory listing that contains all of the cables on the aircraft, sorted by part number. Once a cable is selected, a calibration is performed. Test results are displayed on the system monitor and a clear pass/fail indication is provided. Test results can be printed or forwarded to the engineering department/customer for analysis or saved to hard disk. Software updates can be accomplished via Ethernet port or a CD-ROM supplied by In-Phase Technologies.


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ics, they are looking for certain things to happen," according to Richardson. While these procedures do not constitute "acceptance testing," Richardson calls them the "portion of the delivery where the customer uses the equipment for the purpose for which it is intended." He adds, "Once everything is powered up, it is expected to operate as per the operator's manual." He admits that if a system failure occurs, "There's no reason to think that the coax cable is bad, or that electrical loss is emanating from a poor connection or defective connector or antenna."

Richardson notes that even when customers tested coaxial cables in the field and determined its conformance to specifications, there was still no way to know whether tests were performed properly. "Even when they detect a good signal, when the cable is connected to its antenna and its receiver the performance loss is reduced by some degree to the point that, in a lot of cases, the system is not usable," he says. All of this resulted in substantial waste of time, money, and effort.

As a US Army pilot prior to joining Boeing, Richardson was familiar with the Chinook's avionics systems. After joining Boeing, he was determined to improve the way that these systems and their cables and connectors were being tested. His opportunity came as part of a joint effort with Kocher and key Boeing people, including Richard Hartford, a manufacturing engineering test technician, and Kirk Thompson, a Boeing engineer on the V-22 program.

Typically, there are between 20 and 40 individual coax cable runs in each aircraft. Testing them took weeks to accomplish, sometimes delaying production and ultimate delivery of shipsets to the company's completion centers in other parts of the country. Because the new system is automated, relates Thompson, he "only gets involved now if there's a problem or when a new requirement for a functional test procedure (FTP) comes up, based on new or modified equipment/cables aboard a helicopter." According to Thompson, the new system is so easy to use that "the FTPs tell you step by step what to do, so that someone who is unfamiliar with it from another part of Boeing can open up the FTP, review the step by step test procedure instructions, and move along with the testing." He adds that "we have fewer errors and using the FTP provides an ideal set of guidelines." He noted that programming the system for new cables is straightforward: "We can set parameters for the cable and our video screens will indicate pass/fail modes or display substantially more information about cable performance,

depending upon application."

Boeing's people, the In-Phase group, and D'Ignazio worked together to develop the new automated coaxial cable test system **(Fig. 1)** as well as the FTPs that essentially eliminated previous problems. The automated test system (ATS) not only performs qualitative functions (basically go/no-go testing), but also provides complete statistical data and documentation with regard to precise performance parameters such as insertion loss, frequency roll off, and the distance to a fault **(see sidebar)**. The system also provides an internal confidence test routine, an internal path-loss calibration routine, and pictograms for instructing test operators in connecting cables, detectors, and standards. For distance to fault incidences, the system prompts for propagation factor for the various cable dielectrics. During cable measurements, the system may also be configured for statistical process control functions by archiving all test data into a permanent database.

According the Kocher, "Our new automated test systems are substantially more robust, and eliminate all of the previous variability problems as a result of operator discretion." As evidence, she offers, "In the past few years there have been virtually no field failures of any coax cable runs that have been through the new ATS."

Kocher also said that when the new ATS was first used on the Chinook helicopter it was initially used for testing Nav/Com equipment. Following success with those systems, additional avionics and other Aircraft Protection Systems (APS) were tested as well **(Fig. 2)**. She added that, "Before we received the new ATS, we had to have a much more experienced operator to use the manual systems."

Hartford notes that using the old method on the Osprey took about ten days to "get through all the cables we needed to test, and the failure rate was pretty high." With the new automated system the "failure rate dropped off to practically nothing. It has reduced our entire test time down to about four to five days—about half of the previous time with substantially better results." MRF

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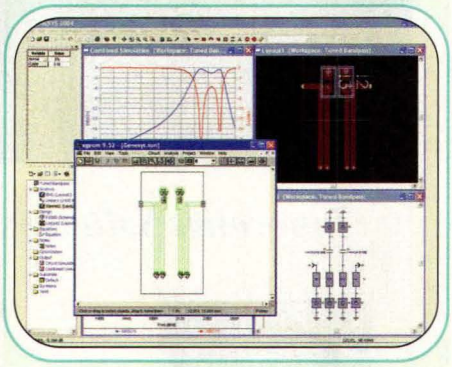

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Growth Is Seen For ON Market

THE OPTICAL-NETWORKING (ON) market will see double-digit growth from 2004 to 2006, according to a study from KMI Research. KMI, an optical-networking market-research company, has released its report, titled *Networking: Worldwide Equipment Markets Update for 2004*. The report concludes that through 2009, the ON market will grow with a 12-percent compound annual growth rate (CAGR). This market, which includes SONET, SDH, DWDM, DXC, and OXC products, was $7.6 billion in 2003 and will reach $15.3 billion in 2009.

KMI's analyses of these ON products include segmentations by vendor, geographic region, and long- vs. short-distance applications. Although metro (short-distance) applications were strong in 2003, the long-distance segment will show a healthy near-term bounce upward for some products, such as DWDM, because systems installed a few years back are filling up. This market growth is driven by bandwidth demand, which is growing at slower rates than in previous years but still fast enough to force new equipment deployments as capacity limits are reached.

Richard Mack, KMI's vice president and general manager, comments, "With carrier capital spending getting stronger, and with the introduction of increasingly versatile transmission equipment, the optical-networking market is returning to annual growth rates in the range of 10 to 20 percent. More importantly, we believe that these growth rates are reasonable and 'healthy' or sustainable, given the input that we've had about bandwidth requirements and budget expectations."

The report is based on a survey of more than 225 individuals with network operations or purchasing responsibilities at telecom carriers, as well as interviews with suppliers and other research. Key findings include:

- Vendors with a strong foothold in Asia—particularly China—have increased their market share.
- This year will see the resumption of positive growth in long-haul DWDM equipment.

For further information, see KMI's website at www.kmiresearch.com. MRF

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1 MHz	-141	-135	-129	-123
10 MHz	-150	-150	-146	-140

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CONTRACTS

Actcom Security Solutions—Has been chosen to provide electronic-access and intrusion-detection systems to critical buildings within the port complexes throughout Virginia.

The contract was awarded to Actcom by Hampton, VA-based Zel Technologies, Inc., the security consulting firm chosen to manage all security projects for the Virginia Port Authority.

Northrop Grumman Corp.—Was awarded a contract by all of the public-safety agencies in Santa Clara, CA to provide an integrated voice-data wireless system that will allow the agencies to communicate effectively while assisting one another during major emergencies. The Silicon Valley Regional Interoperability Project (SVRIP) links all 32 of the municipal and county government public-safety agencies through an integrated voice-data wireless system solution engineered by Northrop Grumman.

Rockwell Collins—Has been selected by the US Air Force for the initial System Design and Development phase of the KG-3X Crytographic Modernization Program, which is designed to provide the US military with strategic communications for airborne portions of the Minimum Essential Emergency Communications Network (MEECN) as well as the Fixed Submarine Broadcast System.

EMS Technologies, Inc.—Announced that EMS's Space & Technology/Atlanta division has been awarded a contract valued at over $2 million to provide the first production lot of phase-shifter kits for the phased-array antenna of an unnamed foreign military radar program.

BAE Systems—Received an $8 million contract from the US Navy to provide 25 AN/USQ-113(V) 3 communications jamming systems for the EA-6B Prowler aircraft.

The EA-6B Prowler is a tactical electronic warfare aircraft that provides day and night lethal and nonlethal electronic-warfare capability for Suppression of Enemy Air Defenses (SEAD).

The work will be performed at the IEWS facility in Hudson, NH, and will be completed in 2006.

FRESH STARTS

Accumet Engineering Corp.—Has contracted Dragon Fire, Inc., an engineering consulting firm, to define, develop, and install four new tools that enable accurate and rapid shape, surface roughness, and dimensional measurements.

Dragon Fire, Inc. developed, supplied, and installed two new instruments, the ATS-150 and the SPU-150, to provide Accumet with the capability of non-contact unconstrained shape measurement that collectively spans a flatness range of 20 millionths to 2 mm.

Plexus Corp.—Announced that revenues for its third fiscal quarter increased 40 percent to $274.8 million, compared to $195.6 million in the prior year period. The company reported a loss for the third fiscal quarter of $0.8 million, equivalent to $0.02 per diluted share. The net loss for the period included $5.5 million ($4.4 million after tax) of restructuring costs, mainly to increase accruals related to previous restructuring actions. Excluding these restructuring costs, the company had pro-forma net income of $3.6 million, the equivalent of $0.08 per fully diluted share.

Skyworks Solutions, Inc.—Announced record revenues of $207.4 million versus guidance of $192.6 million for the third fiscal quarter ended July 2, 2004, up 13 percent sequentially from $183.5 million in the second fiscal quarter. Year-over-year, revenues for the quarter were up 38 percent from $150.2 million.

ANADIGICS, Inc.—Announced second-quarter 2004 net revenues of $22.7 million, up 7 percent sequentially versus guidance of 5 percent. Year-over-year, revenues for the quarter were up 26 percent from $18 million.

Silicon Laboratories, Inc.—Reported record revenue of $126.1 million for the second quarter of 2004. This represented the company's thirteenth-consecutive quarter of revenue growth.

Fluke Corp.—Announced accreditation of the service center at its Everett headquarters. The center was accredited to the stringent ISO/IEC 17025-1999 standard set by the American Association for Laboratory Accreditation (A2LA).

XMA Corp.—Opened its manufacturing facility in Tianjin, China. Located in a new 7500-sq.-ft. facility, this new XMA subsidiary will double XMA's production capacity for RF and microwave terminations, attenuators, and other passive products.

Auriga Measurement Systems, LLC—Announced the acquisition of the characterization instruments, and the test and measurement lines of business as well as the associated assets and personnel from ACCO USA effective August 1, 2004. Auriga has assumed all outstanding orders, warranty, and and support responsibility for these business lines. This acquisition is part of Auriga's strategy to grow the two core business lines of characterization instruments and test and measurement and to expand into related fields that will broaden Auriga's capabilities and consulting activities to support the modeling, design, and manufacturing efforts of its customers.

Auriga will initially operate from 9-11 Goldsmith St., Littleton, MA until it moves to its new facilities at 650 Suffolk St., Lowell, MA 01854 in October 2004.

RF Micro Devices, Inc.—Has announced the opening of a new sales and customer-support office in Shenzhen, China. The office is located in the TianAn Cyber Times Building A in the Fu Tian District. The sales and customer-support office will focus on local Chinese manufacturers, original design manufacturers (ODMs), and international original equipment manufacturers (OEMs) with operations in China. MRF

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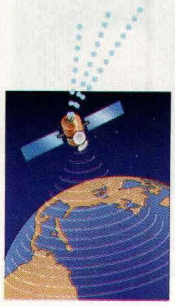

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SPECIFICATIONS

Model	Freq (MHz)	Gain (typ) Midband (dB)	Gain (typ) Flat (±dB)	Max. P_{out}[1] (dBm)	Dynamic Range (Typ @2GHz[2]) NF(dB)	Dynamic Range (Typ @2GHz[2]) IP3(dBm)	I(mA)[3]	Price $ea. (1-9)
ZJL-5G	20-5000	9.0	±0.55	15.0	8.5	32.0	80	129.95
ZJL-7G	20-7000	10.0	±1.0	8.0	5.0	24.0	50	99.95
ZJL-4G	20-4000	12.4	±0.25	13.5	5.5	30.5	75	129.95
ZJL-6G	20-6000	13.0	±1.6	9.0	4.5	24.0	50	114.95
ZJL-4HG	20-4000	17.0	±1.5	15.0	4.5	30.5	75	129.95
ZJL-3G	20-3000	19.0	±2.2	8.0	3.8	22.0	45	114.95
ZKL-2R7	10-2700	24.0	±0.7	13.0	5.0	30.0	120	149.95
ZKL-2R5	10-2500	30.0	±1.5	15.0	5.0	31.0	120	149.95
ZKL-2	10-2000	33.5	±1.0	15.0	4.0	31.0	120	149.95
ZKL-1R5	10-1500	40.0	±1.2	15.0	3.0	31.0	115	149.95

NOTES:
1.Typical at 1dB compression.
2. ZKL dynamic range specified at 1GHz.
3. All units at 12V DC.

ZJL ZKL

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O'CONNELL

Sabritec Names O'Connell As Director Of Operations

Sabritec has appointed DANIEL (DAN) O'CONNELL to the position of director of operations. Prior to joining Sabritec, O'Connell was the vice president of operations at Irvine Electronics, where he specialized in SMT and though-hole PCB manufacturing.

Enthone, Inc.—AARON STORMS to managing director for Enthone-Latin America; formerly general manager for Mexico and human resources director for Latin America at Crompton Corp.

EMS Technologies, Inc.—ALFRED G. HANSEN to the board of directors of the Georgia Technology Authority (GTA); remains as EMS Technologies' president and CEO. Also, STEPHEN NEWELL to director of military sales for the SATCOM Division; formerly senior account manager for the Aeronautical Group, representing EMS's products to Gulfstream, Lockheed Martin, and the US Navy. In addition, JEAN MENARD to director of commercial sales for EMS SATCOM located in Ottawa, Ontario, Canada; formerly employed with BAE Systems, CAL Corp., Innotech Aviation, and Max-Viz, Inc.

Taconic—DENIS BOULANGER to North American sales manager, ADD; formerly sold microwave laminates at Neltec.

Rika Denshi America—AMOS FRIEDNER to sales and marketing manager; formerly employed with Advantest America and Digital Equipment Corp.

Raltron Electronics Corp.—JOHN SHOEMAKE to distribution sales manager; formerly employed at Crystek Crystals Corp.

Integration Associates—LOU DINARDO to the board of directors; continues as president and CEO of Xicor, Inc.

Northrop Grumman Corp.—BERNARD P. MCVEY JR. to vice president and controller for the company's Information Technology (IT) sector; formerly vice president and business manager for the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance and Naval Systems division of the company's Electronic Systems sector.

Falcon Solutions—BURT RABINOWITZ to executive vice president of global supply management; formerly vice president of sourcing and procurement for Alcatel North America.

PCTEL, Inc.—JEFF MILLER to vice president for global sales; formerly headed the Product Management and Marketing division.

Telrad Connegy, Inc.—MICHAEL KRUPNIK to the position of president; formerly vice president of sales with Qwest Communications for their Northeast region spanning from Maine to North Carolina.

Schneider Electric North American OPerating Division—NIC GIHL to vice president of Industrial Automation; formerly president of Proface America and director/co-chairman of Digital Electronics.

GIHL

WEI

ETCO, Inc.—ROCKY WEI to project sales manager; will visit with automotive OEM and aftermarket companies, white goods OEMs, and telecommunications, high technology, and electronic OEM and aftermarket companies.

Connecticut Microwave Corp.—CHARLOTTE ALVAREZ to the engineering staff; formerly a filter engineer at Radio Frequency System. MRF

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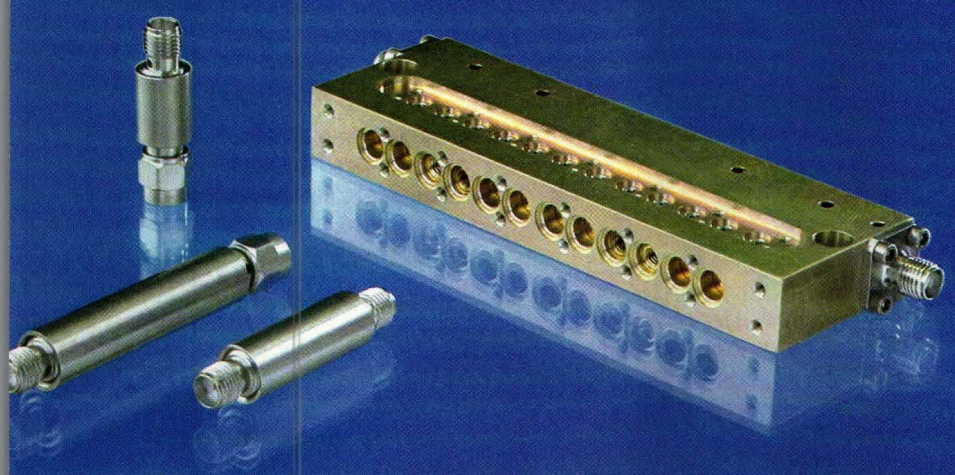

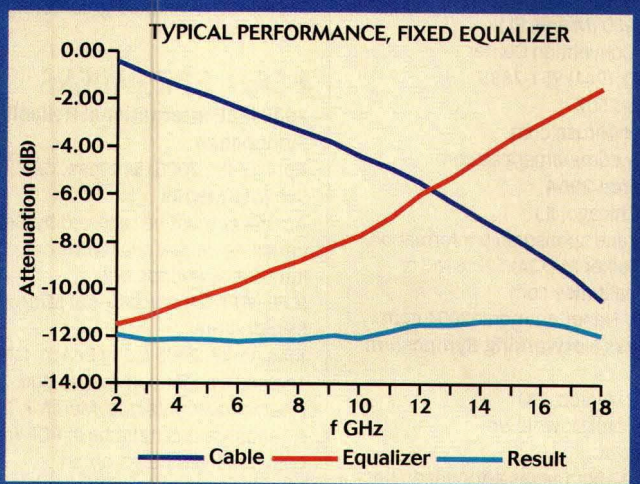

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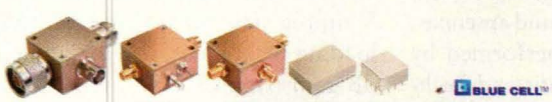

ZNBT ZFBT-FT ZFBT JEBT PBTC TCBT

TYPICAL SPECIFICATIONS

Model	Freq (MHz)	Insertion Loss (dB)	Isolation (dB)	VSWR (:1)	Price $ea. Qty.10
•TCBT-2R5G	20-2500	0.35	44	1.1	8.95*
•TCBT-6G NEW	50-6000	0.7	28	1.2	11.95

TCBT Actual Size .15"x.15" LTCC

•*Patent Pending*

					Qty.1-9
JEBT-4R2G	10-4200	0.6	40	1.1	39.95
JEBT-4R2GW	0.1-4200	0.6	40	1.1	59.95
PBTC-1G	10-1000	0.3	33	1.10	25.95
PBTC-3G	10-3000	0.3	30	1.13	35.95
PBTC-1GW	0.1-1000	0.3	33	1.10	35.95
PBTC-3GW	0.1-3000	0.3	30	1.13	46.95
ZFBT-4R2G	10-4200	0.6	40	1.13	59.95
ZFBT-6G	10-6000	0.6	40	1.13	79.95
ZFBT-4R2GW	0.1-4200	0.6	40	1.13	79.95
ZFBT-6GW	0.1-6000	0.6	40	1.13	89.95
ZFBT-4R2G-FT	10-4200	0.6	N/A	1.13	59.95
ZFBT-6G-FT	10-6000	0.6	N/A	1.13	79.95
ZFBT-4R2GW-FT	0.1-4200	0.6	N/A	1.13	79.95
ZFBT-6GW-FT	0.1-6000	0.6	N/A	1.13	89.95
ZNBT-60-1W	2.5-6000	0.6	45	1.10	82.95

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Built-In Antenna Serves Five Cellular Bands

MINIATURE MULTIBAND ANTENNAS are of interest to any number of manufacturers of cellular communications handsets, since these communications products must now work with any many as four or five different cellular or Personal Communications Services (PCS) frequency bands. Because of this need, Yong-Xin Guo, Michael Yan Wah Chia, and Zhi Ning Chen of the Institute for Infocomm Research in Singapore developed a new design for built-in handset antennas where metal resonators are directly connected to a feedstrip. The researchers applied the design to four-band coverage of GSM900, DSC1800, PCS1900, and UMTS2000 as well as five-band coverage of GSM900, DCS1800, PCS1900, UMTS2000, and ISM2450 bands.

The researchers started with a design consisting of a folded radiating first-layer patch, a second-layer ground plane, supporting foam in between, a short-circuit strip, and a feed strip.The patch is connected to the ground plane via a vertical short-circuited strip and is fed via the feed strip connected to a 50-ohm transmission line etched on the back of the ground plane. By building from this dual-band design, the researchers were eventually able to develop the modified, smaller antennas with radiating strips and resonator elements. Extensive parametric studies were conducted on a variety of designs to examine the effects of ground-plane size, element spacing, substrate thickness, and additional strip thickness and width.

For the five-band design, simulations agreed closely with measurements, showing generation bandwidths around each target band, with only slight differences in operating frequencies. At the highest frequencies (2.45 GHz), the measured gain is around 1.5 dBi. See "Miniature Built-In Multiband Antennas for Mobile Handsets," *IEEE Transactions on on Antennas and Propagation,* August 2004, Vol. 52, No. 8, p. 1936.

SOI CMOS Process Yields 91-GHz TW Amplifier

RESEARCHERS CONTINUE TO PUSH the limits of more traditional semiconductor processes. A case in point is the work performed by Jean-Olivier Pluouchart and Associates with the IBM Semiconductor Research and Development Center in Hopewell Junction, NJ. By using a standard 0.12-µm silicon-on-insulator CMOS microprocess technology, the investigators were able to fabricate a traveling-wave (TW) amplifier with 3-dB bandwidth extending from 4 to 91 GHz.

The TW amplifier was designed without any modifications to the standard process. The process has shown cutoff frequencies in excess of 150 GHz for gate lengths smaller than 60 nm. With optimization, the process has produced maximum frequencies of oscillation in excess of 200 GHz for widths of 2 µm per gate finger.

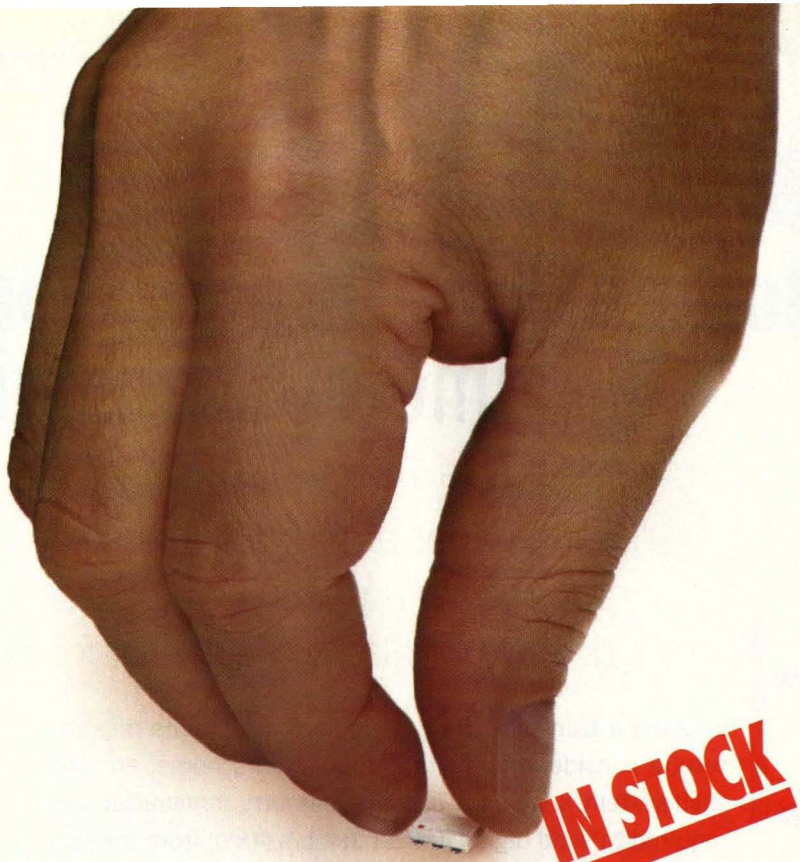
The multistage distributed amplifier design is based on cascaded cells that allow good isolation and high cutoff frequencies. One of the key concerns of the design involved careful consideration of the bypass capacitor values and associated parasitic elements, in order to avoid limiting bandpass characteristics.

Measurements were performed on wafer using a commercial wafer probe station and 110-GHz vector network analyzer system. For 90-mW power consumption, a five-stage design yielded 5 dB gain and 91-GHz cutoff frequency, while a seven-stage amplifier provided 9-dB gain and 86-GHz cutoff frequency with 130-mW power consumption. See "A 4-91-GHz Traveling-Wave Amplifier in a Standard 0.12-µm SOI CMOS Microprocessor Technology," *IEEE Journal of Solid-State Circuits*, September 2004, Vol. 39, No. 9, p. 1455.

TEM Horn Aims At Ground-Penetrating Radars

GROUND-PENETRATING RADARS are invaluable for detection and identification of buried artifacts as well as for security investigations. Such systems require extremely broadband antennas, a motivation for the research performed by Ahmet Serdar Turk of the Scientific and Technical Research Council of Turkey (TUBITAK), Marmara Research Center, Information Technologies Research Institute, Kocaeli, Turkey. The author investigated a ultrawideband (UWB) antenna design for use from 250 MHz to 7 GHz based on a transverse-electromagnetic (TEM) horn structure.

The horn consists of a pair of triangular or circular-slice-shaped conductors that form a V-dipole structure. Using partial-dielectric-loading techniques, the design achieved a 3-dB gain band of 1.5 to 6.0 GHz and 10-dB gain band of more than 25:1 (250 MHz to 7 GHz) with VSWR of typically less than 2.0:1. See "Ultra-Wideband TEM Horn Design For Ground Penetrating Impulse Radar Systems," *Microwave and Optical Technology Letters*, June 5, 2004, Vol. 41, No. 5, p. 333.



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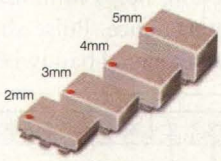

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ADE* TYPICAL SPECIFICATIONS:

MODEL	LO Power (dBm)	Freq. (MHz)	Conv. Loss Midband (dB)	L-R Isol. Midband (dB)	IP3 @Midband (dBm)	Height (mm)	Price ($ea.) Qty. 10-49
ADE-1L	+3	2-500	5.2	55	16	3	3.95
ADE-3L	+3	0.2-400	5.3	47	10	4	4.25
ADEX-10L	+4	10-1000	7.2	60	16	3	2.95
ADE-1	+7	0.5-500	5.0	55	15	4	1.99▲
ADE-1ASK	+7	2-600	5.3	50	16	3	3.95
ADE-2	+7	5-1000	6.67	47	20	3	1.99▲
ADE-2ASK	+7	1-1000	5.4	45	12	3	4.25
ADE-6	+7	0.05-250	4.6	40	10	5	4.95
ADEX-10	+7	10-1000	6.8	60	16	3	2.95
ADE-12	+7	50-1000	7.0	35	17	2	2.95
ADE-4	+7	200-1000	6.8	53	15	3	4.25
ADE-14	+7	800-1000	7.4	32	17	2	3.25
ADE-901	+7	800-1000	5.9	32	13	3	2.95
ADE-5	+7	5-1500	6.6	40	15	3	3.45
ADE-5X	+7	5-1500	6.2	33	8	3	2.95
ADE-13	+7	50-1600	8.1	40	11	2	3.10
ADE-11X	+7	10-2000	7.1	36	9	3	1.99▲
ADE-20	+7	1500-2000	5.4	31	14	3	4.95
ADE-18	+7	1700-2500	4.9	27	10	3	3.45
ADE-3GL	+7	2100-2600	6.0	34	17	2	4.95
ADE-3G	+7	2300-2700	5.6	36	13	3	3.45
ADE-28	+7	1500-2800	5.1	30	8	3	5.95
ADE-30	+7	200-3000	4.5	35	14	3	6.95
ADE-32	+7	2500-3200	5.4	29	15	3	6.95
ADE-35	+7	1600-3500	6.3	25	11	3	4.95
ADE-18W	+7	1750-3500	5.4	33	11	3	3.95
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ADE-1LH	+10	0.5-500	5.0	55	15	4	2.99
ADE-1LHW	+10	2-750	5.3	52	15	3	4.95
ADE-1MH	+13	2-500	5.2	50	17	3	5.95
ADE-1MHW	+13	0.5-600	5.2	53	17	4	6.45
ADE-10MH	+13	800-1000	7.0	34	26	4	6.95
ADE-12MH	+13	10-1200	6.3	45	22	3	6.45
ADE-25MH	+13	5-2500	6.9	34	18	3	6.95
ADE-35MH	+13	5-3500	6.9	33	18	3	9.95
ADE-42MH	+13	5-4200	7.5	29	17	3	14.95
ADE-1H	+17	0.5-500	5.3	52	23	4	4.95
ADE-1HW	+17	5-750	6.0	48	26	3	6.45
ADEX-10H	+17	10-1000	7.0	55	22	3	3.45
ADE-10H	+17	400-1000	7.0	39	30	3	7.95
ADE-12H	+17	500-1200	6.7	34	28	3	8.95
ADE-17H	+17	100-1700	7.2	36	25	3	8.95
ADE-20H	+17	1500-2000	5.2	29	24	3	8.95

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Modulation Choices For Telemetry Transmitters

Selecting the most effective modulation scheme for a portable telemetry transmitter depends on meeting requirements for size, power consumption, and performance.

Designing a transmitter for telemetry applications requires careful consideration of the modulation scheme. For one such system, a weather-balloon telemetry transmitter was required to send digital data at 384 b/s (48 B) from the output of multiple transducers (sensors) used to measure temperature, pressure, humidity, wind speed and Global Positioning System (GPS) data (coordination and time data). The transmitter operates in the low-UHF band using an allocated bandwidth of 4 MHz from 402 to 406 MHz and 200 20-kHz channels.

The transmitter is comprised of three basic sections: baseband, RF stage with frequency synthesizer, and synchronization circuitry. This article will focus on the transmitter's baseband circuitry, including the processing and preparation of signals for the RF stage, such as pulse shaping, error correction, coding, interleaving, and modulation.

Pulse shaping helps minimize the effects of interference. Pulse shaping typically limits a signal bandwidth for processing through an in-phase/quadrature (I/Q) modulator:

$$s(t) = \sum_{n=-\infty}^{\infty} d(n)g(t-nT) \qquad (1)$$

where:

d(n) = the input data (binary or multilevel data),

g(t) = the pulse shape signal, and

s(t) = the shaped signal.

A variety of pulse shapes can be used to limit bandwidth, including raised-cosine and Gaussian forms. In the time domain, the raised-cosine form has the form

$$g(t) = \frac{\sin(\pi t/T)}{\pi t/T}\,\frac{\cos(\pi rt/T)}{1-4r^2t^2/T^2} \qquad (2)$$

DR. TUFIK BUZID
Professor
Albert-Ludwigs Universität Freiburg
IMTEK-Institute for Microsystem Technology
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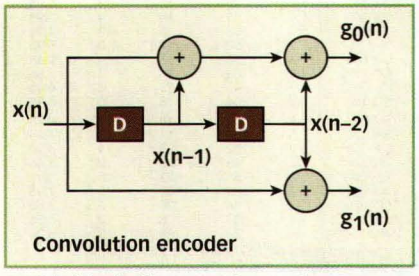
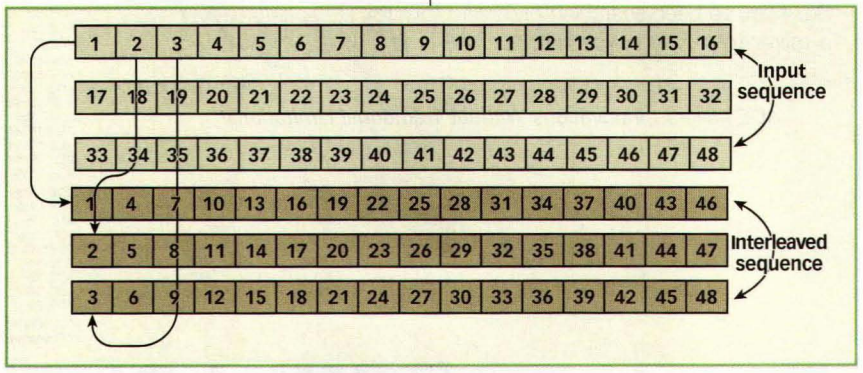


1. This block diagram shows the component parts of a simple convolution coder.



2. This diagram illustrates the interleaving process used to improve BER in noisy environments.

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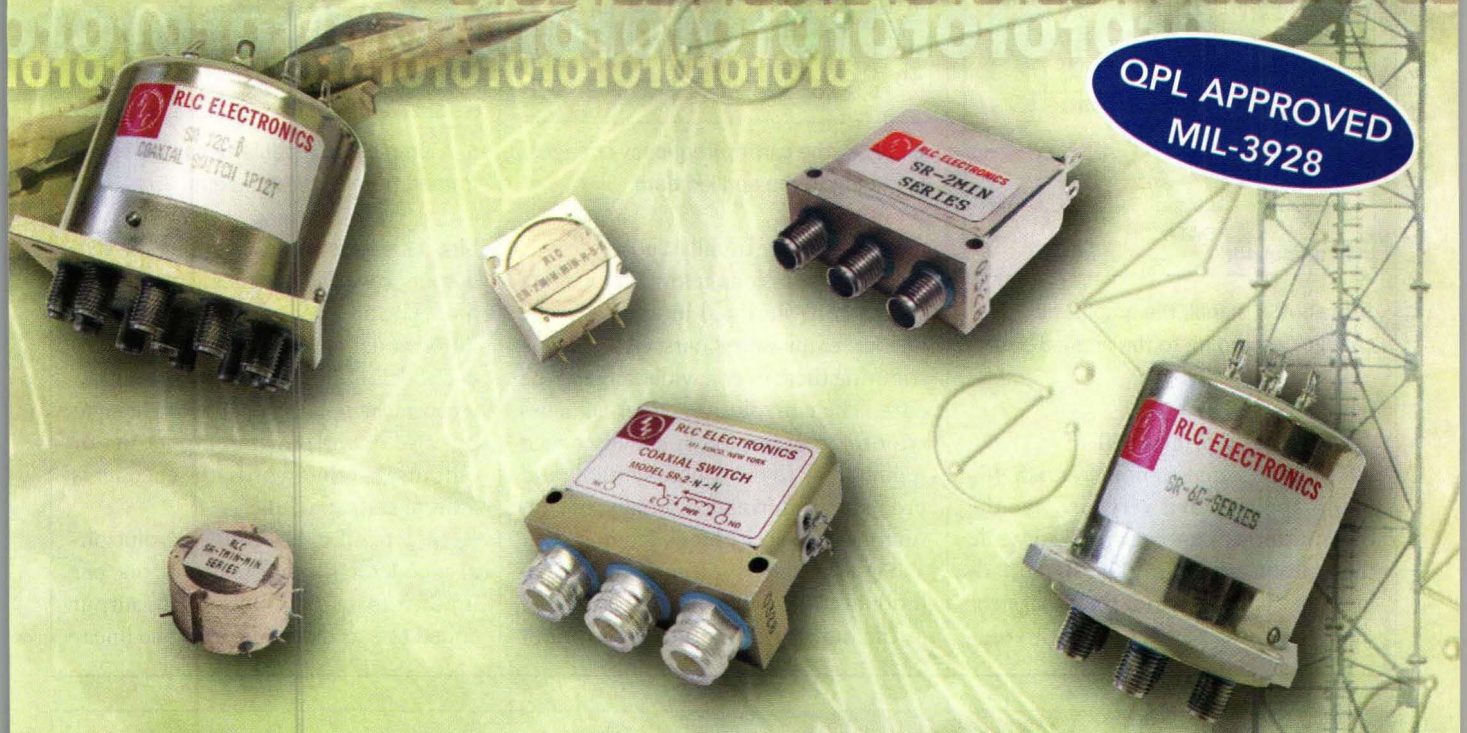

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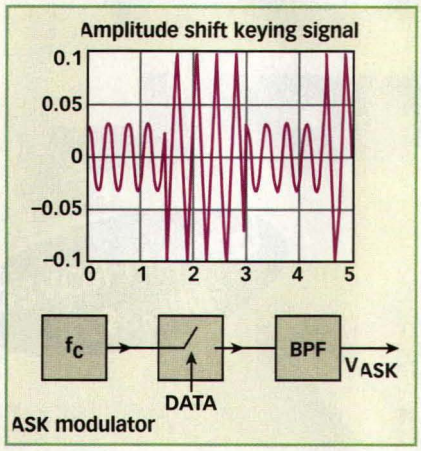
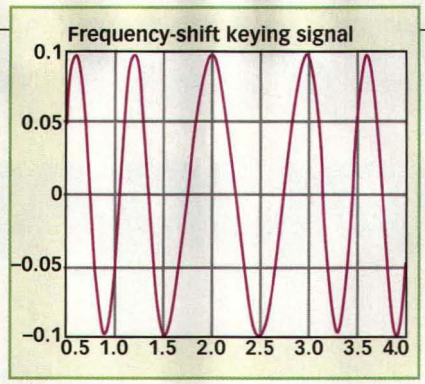
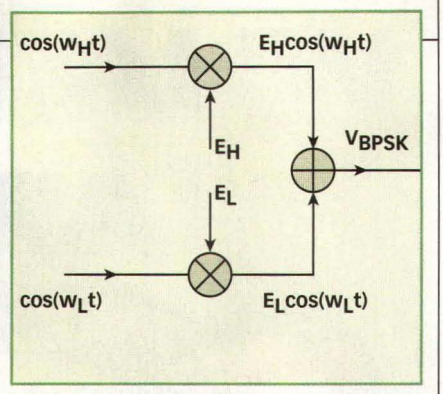


3. In an ASK signal, the amplitude changes according to the applied data.



4. In FSK, the carrier frequency changes according to the applied data.



5. A simple FSK modulator can be formed from a pair of mixers.

where:

r = the rolloff factor ($0 < r < 1$).

Since the signal-to-noise ratio (SNR) in this application is very low, and the transmitter cannot be stabilized while the balloon is rising, some signal fading is inevitable, requiring the use of error detection and correction. Convolutional coders are usually a good idea for digital transmissions at low SNRs, along with a convolutional interleaver. The interleaver minimizes burst errors by distributing them over a wide range of the data. The convolution coder achieves error-free transmission by adding enough redundancy to the source symbols and process the information serially, or continuously, in short block lengths.

Figure 1 shows a four-state convolutional coder where the rate is defined as the number of input bits to output bits. This system has one input and two outputs, resulting in a coding rate of one-half. The number of states of a convolution coder is determined by the number of delay units (memory); the output is dependent not only on the current input but also on the previous inputs and or outputs. In other words, the encoder is a finite state machine.

In general, a k/n-rate convolutional encoder has k shift registers, one per input information bit, and n output coded bits as determined by the linear

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combinations (with exclusive-or gates) of contents of the registers and the input information bits. When the ratio is 1/n, then a technique known as puncturing can be applied to achieve higher-rate convolutional encoders.

The shape of the coder is determined by the generators or generator sequences:

$$G_0(n) = x(n) + x(n-1) + x(n-2) \quad (3)$$

$$G_1(n) = x(n) + x(n-2) \quad (4)$$

The generator can be written as a polynomial in D where D is a unit delay:

$$g_0(n) = 1 + D + D^2 \quad (5)$$

$$g_1(n) = 1 + D^2 \quad (6)$$

The generators can be represented in binary form as g_0 = [1 1 1] and g_1 = [1 0 1] where 1 represents a connection with the exclusive-or adder and 0 represents no connection. They can also be represented in an Octal system as [7, 5]. Different generators were used in the current system, with the convolution of [171, 131] generators realized using the MATLAB mathematical analysis/simulation program from The MathWorks (Natick, MA).

Under multipath conditions, an interleaver is needed in a transmitter to improve the bit-error rate (BER). In the current application, a convolutional interleaver was used with a convolutional encoder. In the interleaving process **(Fig. 2)**, each small cell represents a bit, with adjacent bits distributed for ease of recovery at the receiver.

There are many important criteria in choosing the correct modulation method, including the total cost of the transmitter, the size and power supply, and the required mobility of the transmitter. For the current application, the transmitter is disposable and used only once or twice and so must be low in cost. The transmitter should also be small and light in weight. The transmitter is designed to run on a +9-VDC battery power supply. The limited power supply mandates that the transmitter operate under nonlinear conditions, implying the use of a constant-envelope modulation method.

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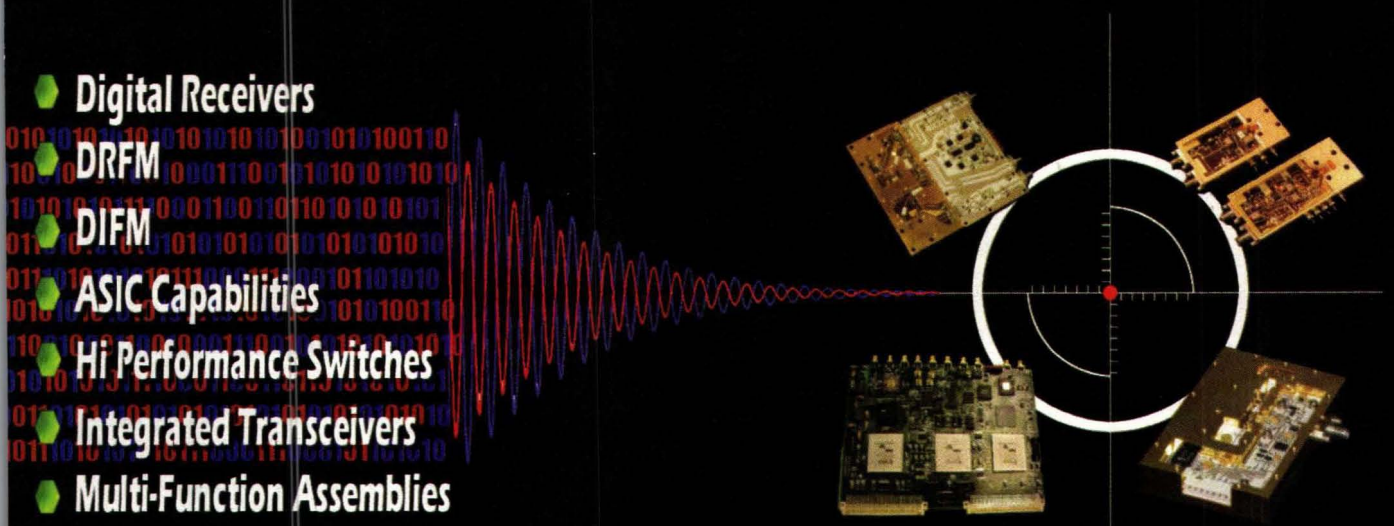

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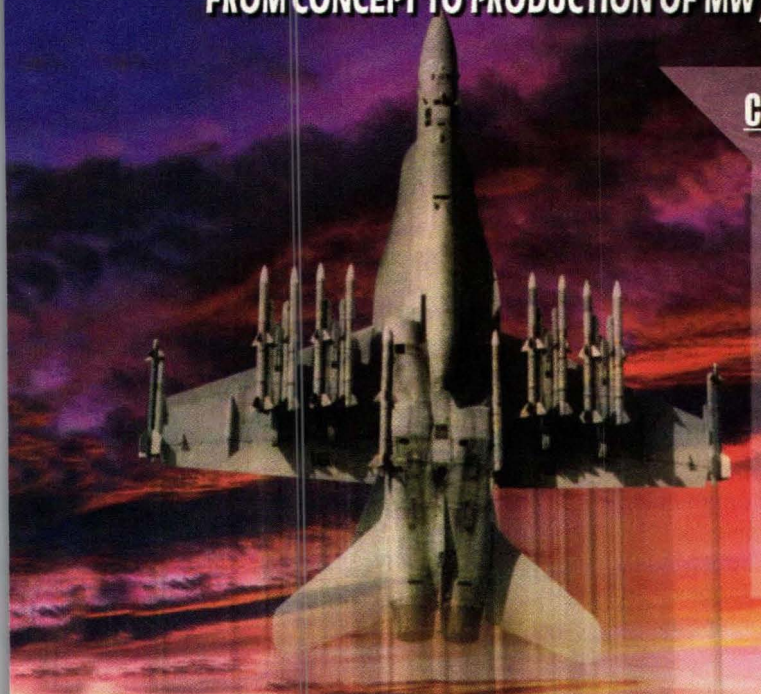

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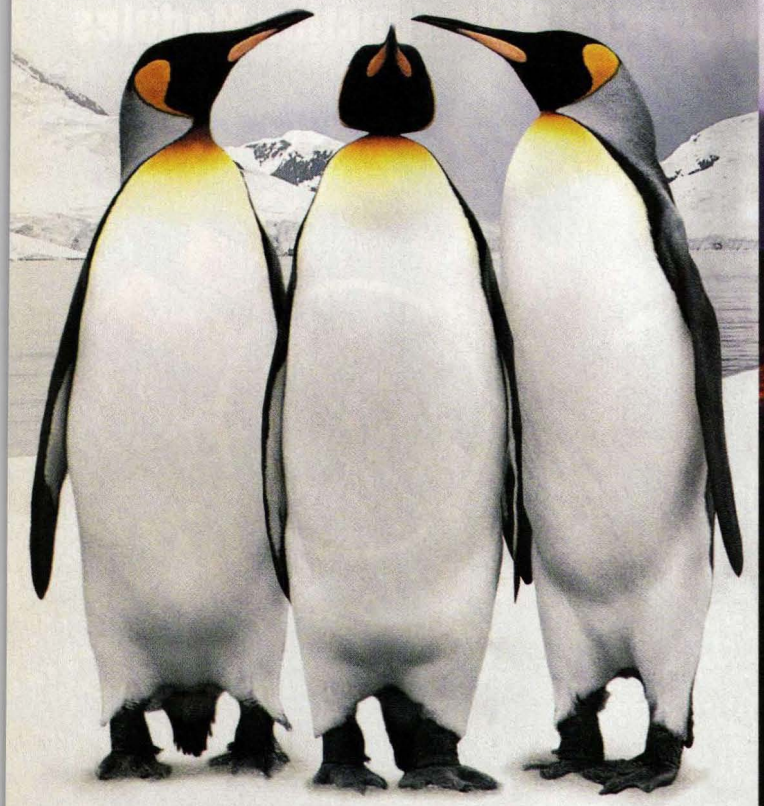

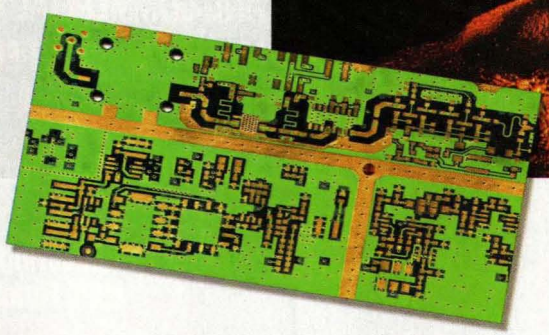

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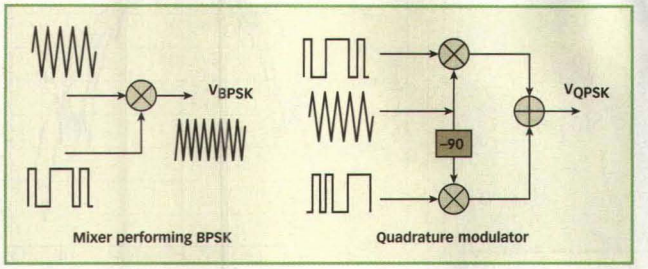
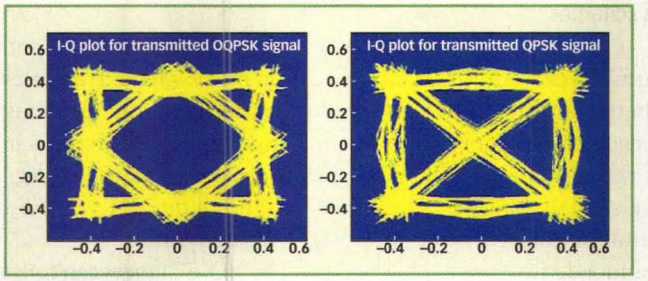


6. A mixer-based modulator (left) is compared to a more complex quadrature modulator (right).



7. These plots compare OQPSK (left) and QPSK (right).

Due to the mobility (movement) of the transmitter, oscillation and Doppler effects are a concern that can result in dead zones where the receiver has no signal. Convolutional coding helps minimize loss of data due to Doppler, fading, and multipath effects, although it imposes an additional load on the system data processor and rise in power consumption. By careful selecction of modulation format for efficiency, it should be possible to meet the system performance requirements even under +9-VDC battery power.

In amplitude-shift keying (ASK), the amplitude of the carrier fluctuates according to the transmitted data. In binary transmission, the carrier amplitude will exhibit one of two values **(Fig. 3)**. Due to the fluctuation of the signal amplitude, this modulation method by itself is not effective in noisy channels, but is often combined with other modulation schemes to improve system spectral efficiency.

By using frequency as the modulation parameter, frequency-shift-keying (FSK) results. When a carrier frequency is modulated by a binary data, two frequencies are produced **(Fig. 4)**. Frequency separations (frequency deviations) can be chosen such that orthogonal ($\pi/2$ phase) transmission is achieved. FSK modulation is quite effective in the presence of noise, but imposes wider spectrum bandwidth requirements compared with other modulation formats such as phase modulation. The bandwidth of binary FSK (BFSK) is BW = $4f_b$, where f_b is the baseband data rate, or:

$$v_{BFSK}(t) = E\cos(w_0 t + d(t)\Omega t) \qquad (7)$$

where:

d(t) = +1 or −1 according to the binary input data and

Ω = a constant offset.

The transmitted signal is either

$$v_{BFSK}(t) = E\cos(w_0 t + \Omega t) \quad (8)$$

or

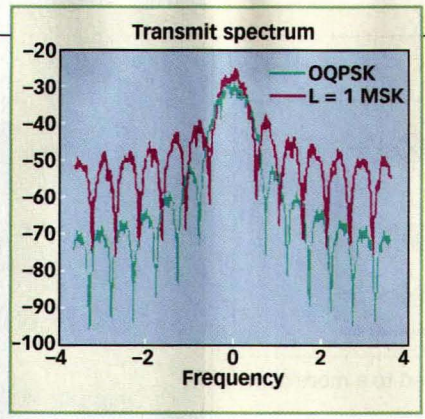
$$v_{BFSK}(t) = E\cos(w_0 t - \Omega t) \quad (9)$$

The signal has an angular frequency of $w_H = w_0 + \Omega$ or $w_L = w_0 - \Omega$. BFSK signals can be generated with the simple modulator of **Fig. 5**. In this configuration, two balanced modulators are used alternately, one with carrier w_H and the other with carrier w_L. Amplitudes E_H and E_L are generated according to the table so that the modulator functions like a switch. Accordingly, the BFSK signal can be rewritten as Eq. 10, which is comparable to binary phase-shift keying (BPSK). In BFSK, the amplitude of the two terms alternate between 0 and 1 (antipodal), while in BPSK the amplitude alternates between –1 and +1 (bipolar). The distance between BFSK signal end points is smaller than the distance separating points of BPSK signals. The BFSK and BPSK schemes can be further compared by means of the trigonometric identity of Eq. 11, or the alternate equivalent expression of Eq. 12.

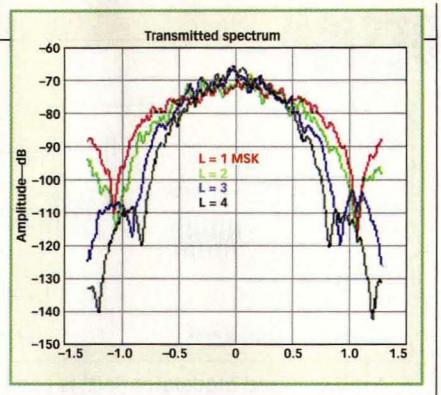
The first term carries no information. The second term in this equation is similar to BPSK, with the minor difference that the data is shaped by sinΩt. As a result, BFSK does not share the noise resistance of BPSK.

Multifrequency shift keying involves the transmission of multilevel rather than binary data. The total required bandwidth (B) in this case is B = 2Mf where M is the number of symbols and f_s is the symbol rate. As a result, M-ary FSK requires more bandwidth than other modulation schemes such as M-ary PSK. The probability of error decreases as M increases, compared to other modulation schemes, such as BPSK.

In phase-shift keying (PSK), the phase of the carrier is altered according to the data. By maintaining roughly constant amplitude, the approach provides good noise resistance. The spectrum efficiency can be dramatically improved by combining both PSK with ASK. BPSK, which can be thought of as an AM signal, can be generated by sending a waveform as a carrier to a balanced modulator and applying the baseband signal as the modulating waveform. A typical



8. This spectral plot compares QQPSK and MSK modulation schemes.



9. This CPM spectrum plots signals based on different values of L.

PSK signal spectrum reveals about 14 dB difference between the sidelobe and mainlobe levels (where more than 90 percent of the signal power is found). Such high sidelobes can cause adjacent-channel interference so they must be reduced. Lowpass filtering of the baseband signals helps to suppress (although not eliminate) the unwanted sidelobe signals. Unfortunately, spectrum suppression tends to distort the desired signal, resulting in a partial overlap of a data bit and its adjacent bits in a single channel, a phenomenon known as intersymbol interference (ISI). ISI can be minimized through equalization filters.

Figure 6 shows how a single mixer can be used to modulate a carrier by alerting its amplitude or phase or frequency, resulting in two information states, where one represents one or zero. In contrast, quadrature modulators offer the advantage that any parameter of a carrier can be simultaneously manipulated to represent the information. A quadrature modulator is implemented with a phase shifter, two mixers, and signal-combining stage.

The representation of a quadrature modulator generating a quadrature-phase-shift-keying (QPSK) signal is Eq. 13,

where:

$d_e(t)$ = even indexed data and

$d_o(t)$ = odd indexed data.

The abrupt changes in phase of a QPSK baseband signal give rise to spectral components at high frequencies and relatively wide spectral width. The baseband spectral range is large and multiplication by the carrier translates the spectral pattern without changing its form. The abrupt phase changes in QPSK (which can be as large as 180 deg.) occur at the symbol rate $1/T_s = 0.5T_b$, where T_b is the data rate.

Such abrupt phase changes can cause substantial changes in the amplitude of the waveform, causing problems in QPSK communication systems. Most systems employ nonlinear power output stages in their transmitters to suppress the amplitude variations. Because of their nonlinearities, however, these stages generate spectral components outside the range of the main signal lobe thereby undoing the effect of the band-limiting filtering and causing interchannel interference. Staggered or offset QPSK (OQPSK), with phase changes limited to 90 deg., is often substituted for 180-deg. QPSK. By limiting shifts to 90 deg., the data arms are delayed to each other by one-half period of the data rate and the signal envelop never goes to zero. BERs for QPSK and OQPSK are the same as for BPSK **(Fig. 7)**.

An important feature of minimum-shift keying (MSK) is its phase continuity. MSK is generated in the same manner as offset QPSK provided that the transmitted data is shaped using a one-half-cycle sinusoid. The MSK signal has constant signal envelop and avoids the 90-

$$v_{BFSK}(t) = E_H\cos(w_H t) + E_L\cos(w_L t) \quad (10)$$

$$\cos\theta = \cos -\theta, \textit{ and } \sin\theta = -\sin -\theta \quad (11)$$

$$v_{BFSK}(t) = E\cos(\Omega t)\cos(w_0 t) - E\,d(t)\sin(\Omega t)\sin(w_0 t) \quad (12)$$

$$v_{QPSK}(t) = E\,d_e(t)\cos(wt) + E\,d_0(t)\sin(wt) \quad (13)$$

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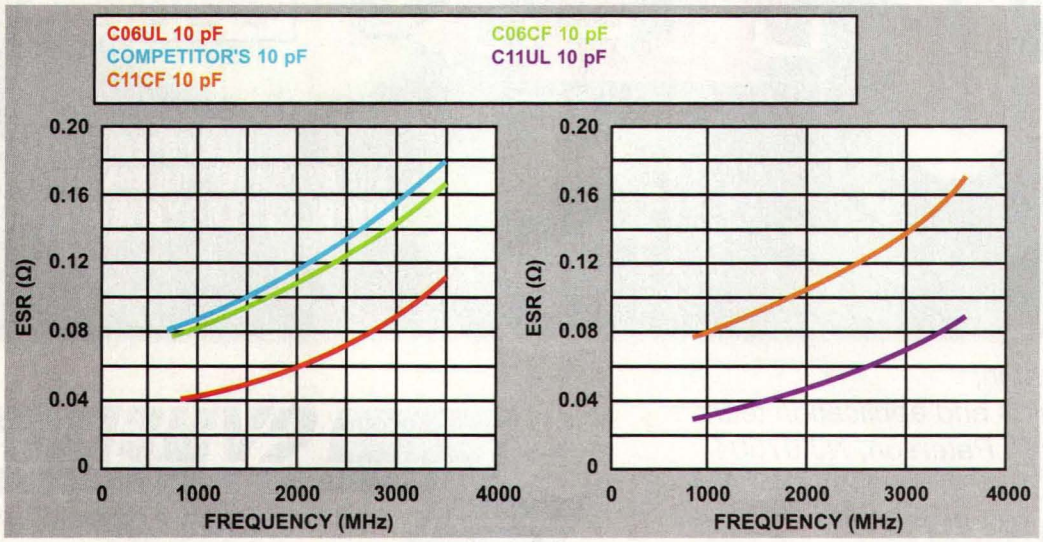

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deg. abrupt phase shift that occurs in OQPSK. In MSK, the baseband waveform, which multiplies the quadrature carrier, is much smoother than the abrupt rectangular waveform of OQPSK. While the spectrum of MSK has a main lobe which is 1.5 times as wide as the main lobe of QPSK, the side lobes in MSK are smaller **(Fig. 8)**, making filtering much easier.

An MSK signal can be represented mathematically by Eq. 14. An MSK signal is a quadrature signal where each term is multiplied by the data. This data is shaped by a sinusoid for the purpose of smoothing. As it appears as a modified version of OQPSK, it can be called "shaped OQPSK." MSK signals can be formatted to appear as FSK signals.

By using the trigonometric identity, the MSK equation can be written as Eq. 15. The magnitudes of the two terms can be replaced by E_H and E_L in Eq. 16, and the MSK signal appears as Eq. 17.

When the data $d_e(t)$ and $d_o(t)$ are the bipolar values +1 and –1, then E_H and E_L simultaneously take on the values of 0 and 1, respectively. The transmitted signal appears as FSK with angular frequency of w_H or w_L although maintaining constant amplitude. For orthogonality over the bi interval T_b, the following must be satisfied:

$$\int_0^{T_b} \sin(w_H t)\sin(w_L t)dt = 0 \qquad (18)$$

Recalling the trigonometric identity 2sin(A)sin(B) = cos(A + B) – cos(A – B), it can be seen that orthogonality is preserved when

$$2\pi(f_H - f_L)\,T_b = n\pi \qquad (19)$$

$$2\pi(f_H + f_L)\,T_b = m\pi \qquad (20)$$

resulting in Eq. 21.

The minimum difference between f_L and f_H is obtained when m – n = 1 and when $f_L \neq 0$. For the minimum n = 1 and m = 2, the result is $f_H = 3f_b/4$ and $f_L = f_b/4$. When $w_L - w_H = 2\,\Omega$, then $\Omega = 2\pi(f_b/4)$. For this reason, this modulation scheme is called minimum-shift keying (MSK).

So far, input data has been half-sinusoidal shaped. With Gaussian MSK (GMSK), input data are shaped using a Gaussian pulse shape so that phase oscillation is reduced to less than $\pi/2$ compared to MSK and transitions between phase states are smoother.

The mathematical representation of the Gaussian pulse shape is

$$g(t) = \sqrt{\frac{2\pi}{\ln 2}}\beta \exp\left(-\frac{2\pi^2\beta^2 t^2}{\ln 2}\right) \qquad (22)$$

where:

β = the 3-dB bandwidth.

In a continuous-phase-modulation (CPM) scheme, the phase of the carrier is changed even more smoothly. To maintain this smooth phase continuity, however, the history of previous symbols must be stored in memory (L). When L = 1, this modulation scheme is known as a full-response system or binary CPM (which defines an MSK scheme). A partial response CPM scheme is when L is greater than 1. This has advantages compared to OQPSK or MSK in that it ensures rapid spectral rolloff as well as a narrower spectrum **(Fig. 9)**.

When the MSK and GMSK modulators were simulated with MATLAB and Simulink, the power levels at the channel boundaries were better than –80 dBc for a case where the maximum allowable level of adjacent-channel power must be better than –60 dBc according to wireless regulations. From these simulations, both modulators meet the requirements. MRF

$$v_{MSK}(t) = E\,d_e(t)\,\sin(\Omega t)\,\cos(w_0 t) + E\,d_0(t)\,\cos(\Omega t)\,\sin(w_0 t) \qquad (14)$$

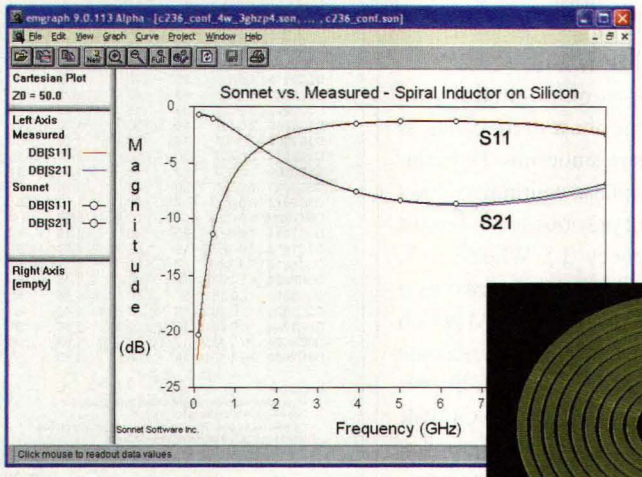
$$v_{MSK}(t) = E\left[\frac{d_e(t)+d_0(t)}{2}\right]\sin(w_0+\Omega)t + E\left[\frac{de(t)-d_0(t)}{2}\right]\sin(w_0-\Omega)t \qquad (15)$$

$$E_H = (d_e(t)+d_0(t))/2 \text{ and } E_L = (d_e(t)-d_0(t))/2 \qquad (16)$$

$$v_{MSK}(t) = E_H \sin(w_H t) + E_L \sin(w_L t) \qquad (17)$$

$$f_H = (m+n)f_b/4 \text{ and } f_L = (m-n)f_b/4 \qquad (21)$$

follow the curve...



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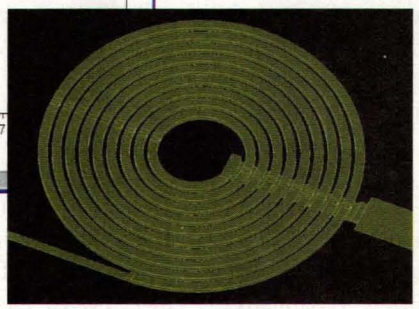

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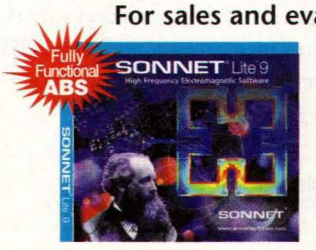

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DESIGN

Approach Increases Amplifier Gain

The unilateral gain design technique can be applied to tune a transistor's input and output circuitry for more gain.

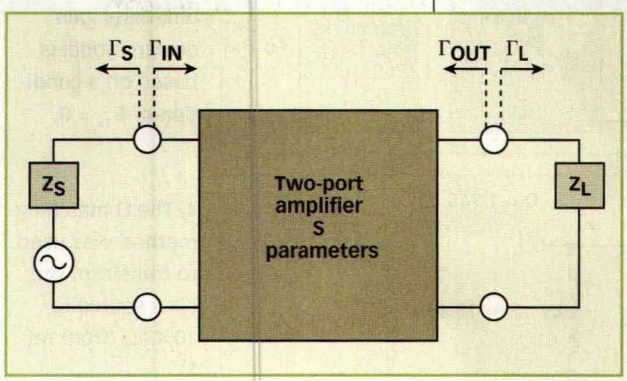
JOSEPH F. WHITE
JFW Technology, Inc., e-mail: jwhite@ieee.org.

Amplifier performance can be enhanced by understanding the electrical requirements of the active device, the transistor. As was seen last month in the second part of this article series, adding the appropriate stabilizing circuitry can make a transistor unconditionally stable so that it does not oscillate at any frequency regardless of source and load impedances. This third part of the article series will show how to tune the input and output of the transistor to obtain higher gain using the unilateral gain design method.

It has been shown that S-parameters are a valuable aid both for collecting data for a transistor and then using the data to predict performance and design an amplifier circuit. As noted in Part 1, unlike Z, Y, or ABCD parameters, the values of S-parameters depend not only upon the properties of the transistor but also upon the source and load circuits used to measure them. This is because they measure transmitted and reflected waves, and these depend upon both the transistor and the source and load used to test it **(Fig. 1)**.

The concepts of a reflection coefficient and traveling waves can be used even if there are no actual transmission lines at the device ports. One might expect that the input reflection coefficient, Γ_{IN}, would simply be equal to S_{11}, and that Γ_{OUT} would be equal to S_{22}. However, because of feedback these must be corrected (see page 214 of ref. 1):

SEE EQ. 1 IN BOX BELOW



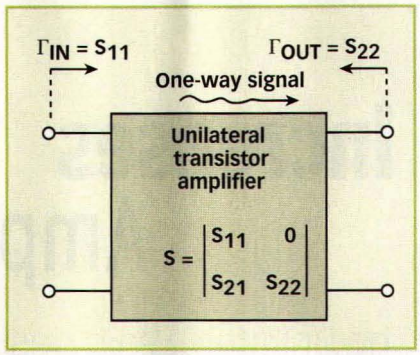
1. This simple diagram shows input and output reflection coefficients.

$$\Gamma_{IN} = S_{11} + \frac{S_{12}\,S_{21}\,\Gamma_L}{1 - S_{22}\,\Gamma_L} \quad and \quad \Gamma_{OUT} = S_{22} + \frac{S_{12}\,S_{21}\,\Gamma_S}{1 - S_{11}\,\Gamma_S} \qquad (1a,b)$$

$$G_T = \frac{Power\ delivered\ to\ load}{Power\ available\ from\ the\ source} \qquad (2)$$

$$G_T = \frac{P_{LOAD}}{P_{AVAIL}} = \frac{1 - |\Gamma_S|^2}{|1 - \Gamma_{IN}\,\Gamma_S|^2} |S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\,\Gamma_L|^2} \qquad (3a)$$

$$G_T = \frac{1 - |\Gamma_S|^2}{|1 - S_{11}\,\Gamma_S|^2} |S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - \Gamma_{OUT}\,\Gamma_L|^2} \qquad (3b)$$



2. This representation illustrates input and output reflection coefficients for the unilateral gain assumption

The general transducer gain of a two-port network having S_{21} and S_{12} values, whether it is a transistor or not, is

SEE EQ. 2 IN BOX ON P. 65

SEE EQ. 3 IN BOX ON P. 65

$$G_{TU} = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (4)$$

$$G_{S-MAX} = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2} = \frac{1-|S_{11}|^2}{\left(1-|S_{11}|^2\right)^2} = \frac{1}{1-|S_{11}|^2} \quad (8)$$

If $S_{12} = 0$, then $\Gamma_{IN} = S_{11}$ and $\Gamma_{OUT} = S_{22}$. Furthermore, if $S_{12} = 0$, the transducer gain becomes (see page 228 of ref. 1):

SEE EQ. 4 IN BOX ABOVE

This can be considered as three separate gain factors:

$$G_{TU} = G_S\ G_0\ G_L \quad (5)$$

in which

$$G_S = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2} \quad (6a)$$

$$G_0 = |S_{21}|^2 \quad (6b)$$

$$G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (6c)$$

The unilateral gain **(Fig. 2)** expressions of Eq. 3 apply for any Γ_S and Γ_L. To maximize G_S, the value of Γ_S is first selected as:

$$\Gamma_S = S_{11}^* \quad (7)$$

Then

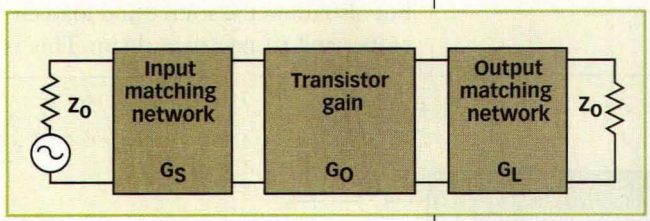
SEE EQ. 8 IN BOX BELOW

Similarly, to maximize G_L, the value of Γ_L is selected as

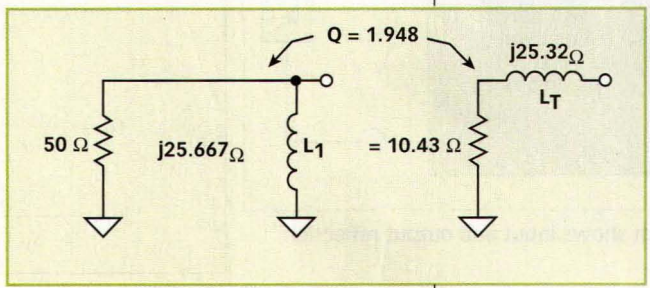
$$\Gamma_L = S_{22}^* \quad (9)$$

and then

$$G_{L-MAX} = \frac{1}{1-|S_{22}|^2} \quad (10)$$



3. This three-stage, unilateral gain design model is based on a condition of $S_{12} = 0$.



4. The Q matching method was used to transform the 50-Ω source to 10.43 Ω (from ref. 2).

Since under the unilateral assumption, $S_{12} = 0$, the maximum gain to be obtained from a transistor is:

SEE EQ. 11 IN BOX AT RIGHT

The overall gain (in dB) to be obtained is then **(Fig. 3)**

SEE EQ. 12 IN BOX AT RIGHT

in which it should be recognized that G_S and G_L are the gains (or losses) to be obtained by matching (or deliberately further mismatching) the input and output circuits, respectively. Of course, there is an error in the gain calculations of Eqs. 8 and 9 if in the actual transistor $S_{12} \neq 0$. In that case, the true gain, G_T, is related to the calculated unilateral gain G_{TU} by (see page 239 of ref. 1):

$$\frac{1}{(1+U)^2} < \frac{G_T}{G_{TU}} < \frac{1}{(1-U)^2} \qquad (13)$$

where:

$$U = \frac{|S_{11}||S_{21}||S_{12}||S_{22}|}{\left(1-|S_{11}|^2\right)\left(1-|S_{22}|^2\right)} \qquad (14)$$

The value of U varies with frequency because of its dependence on the S-parameters and it is called the unilateral figure of merit. For the 2N6679A transistor, applying the S-parameter values at 1 GHz from Table 10.1-1, U is calculated as:

$$U = \frac{(0.68)(6.6)(0.03)(0.46)}{\left(1-0.68^2\right)\left(1-0.46^2\right)} \qquad (15)$$

SEE EQ. 16 IN BOX ON P. 70

SEE EQ. 17 IN BOX ON P. 70

From this it can be seen that the

Table 1: Revised S-parameters for the stabilized 2N6679A amplifier

	MAGNITUDE	ANGLE
S_{11}	0.661	-162.8^0
S_{21}	6.25	83.23^0
S_{12}	0.028	59.23^0
S_{22}	0.414	-31.86^0

$$G_{TU-MAX} = \frac{1}{1-|S_{11}|^2}|S_{21}|^2\frac{1}{1-|S_{22}|^2} \qquad (11)$$

$$G_{TU}(dB) = G_S(dB) + G_0(dB) + G_L(dB) \qquad (12)$$

Table 2: Input and output impedances for the stabilized 2N6679A amplifier

Z_{IN}	Z_{OUT}
(10.43 – j7.238) Ω	(88.493 – j46.646) Ω

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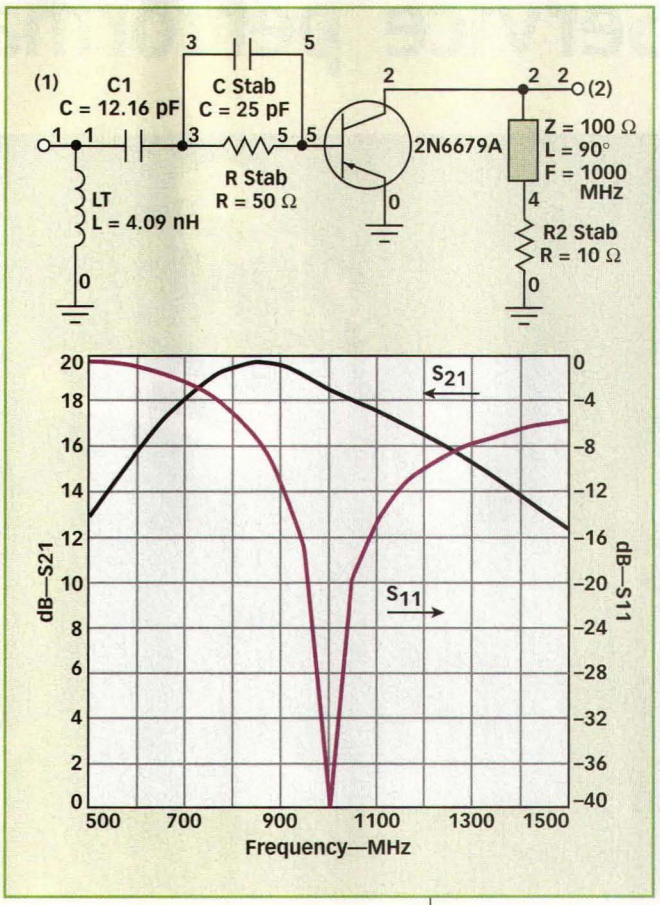


5. This plot shows the S_{21} and S_{11} performance of the stabilized 2N6679A with unilaterally matched input.

unilateral gain approximation can be used for the 2N6679A at 1 GHz with an error no greater than 1.4 dB. To obtain the "maximum gain" using the unilateral gain design, the 50-Ω source is transformed to $Z_S = Z_{IN}^*$, and the 50-Ω load is transformed to $Z_L = Z_{OUT}^*$. From the S-parameters,

$$z_{IN} = \frac{1+S_{11}}{1-S_{11}} \text{ and } z_{OUT} = \frac{1+S_{22}}{1-S_{22}} \quad (18)$$

To unnormalize,

$$Z_{IN} = z_{IN}Z_0 \text{ and } Z_{OUT} = z_{OUT}Z_0 \quad (19)$$

Since the S-parameters have been modified by adding the stabilizing components, revised S-parameters must be used for the stabilized 2N6679A transistor circuit. This would be a laborious task, but is easy and straightforward using network simulator software. The revised S-parameters are shown in **Table 1.**

There are numerous methods by which the amplifier can be matched. As an example, the Q matching method can be employed.[2] To transform a resistance R_H to a lower value R_L, place a reactance in parallel with it having magnitude R_H/Q. Converting to the series equivalent circuit results in a series resistance $R_L = R_H/(1 + Q2)$. Then resonate the equivalent series reactance with a reactance of the opposite sign. Since the input impedance at 1 GHz is

$$Z_{IN} = 10.43 - j7.238\ \Omega \quad (20)$$

it is necessary to transform the 50-Ω source to ZIN*. Thus,

$$Z_S = 10.43 + j7.238\ \Omega \quad (21)$$

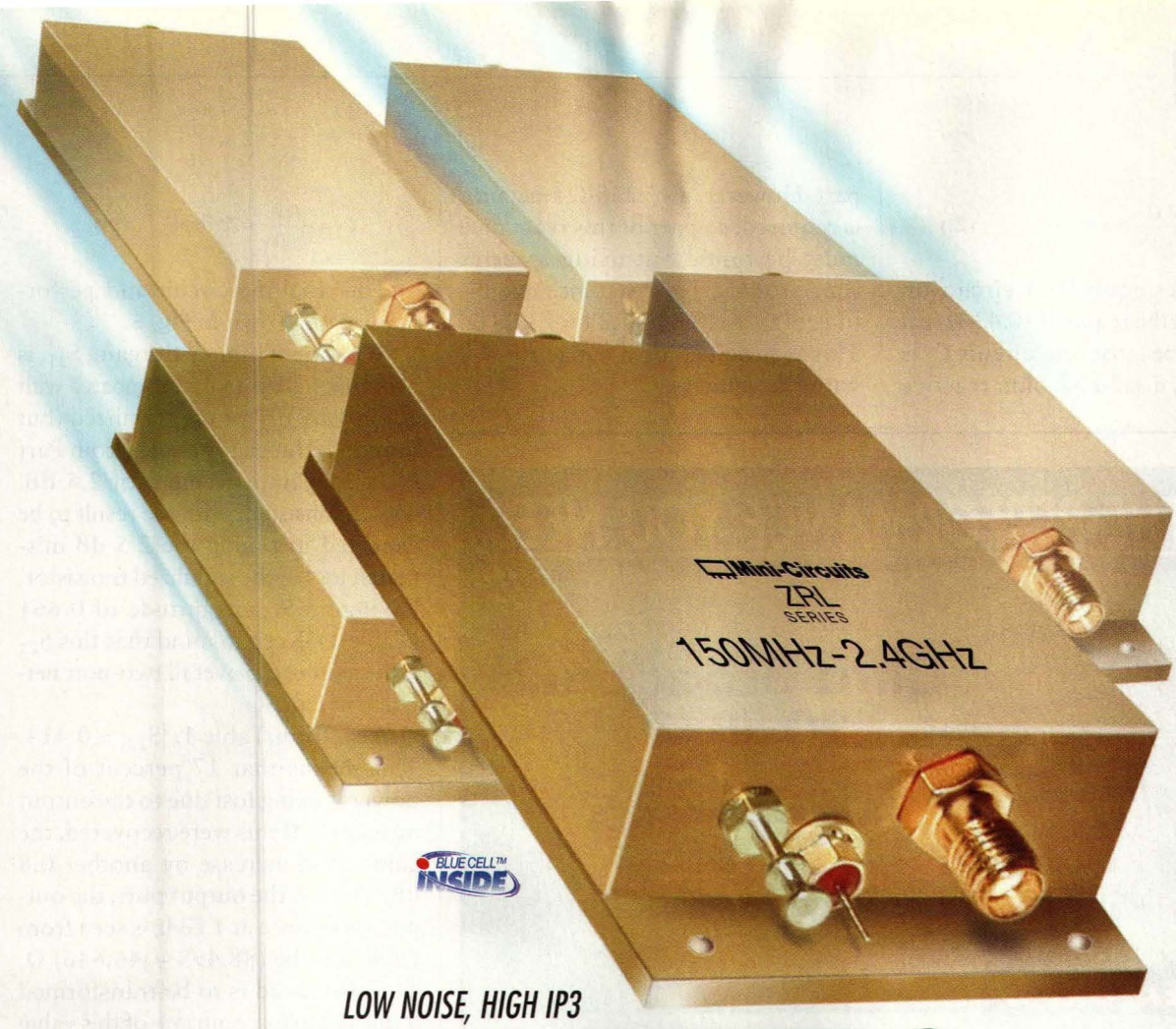
The process begins by transforming the 50-Ω source to 10.43 Ω:

$$\frac{50}{10.43} = 4.794 = 1+Q^2$$
$$Q = 1.948 \quad (22)$$

Since the transformation from 50 Ω is to a lower resistance **(Fig. 4)**, the conversion begins with a shunt reactance in parallel with the 50 Ω. Since the final transformed value for Z_S has an inductive part, a shunt inductor is selected rather than a capacitor. For a Q of 1.948, the reactance of L1 is +25.667 Ω. This can be provided using an L_1 given by:

$$\frac{1}{(1-U)^2} = \frac{1}{(1-0.146)^2} = 1.37 = +1.37\ dB \quad (16)$$

$$\frac{1}{(1+U)^2} = \frac{1}{(1+0.146)^2} = 0.76 = -1.18\ dB \quad (17)$$



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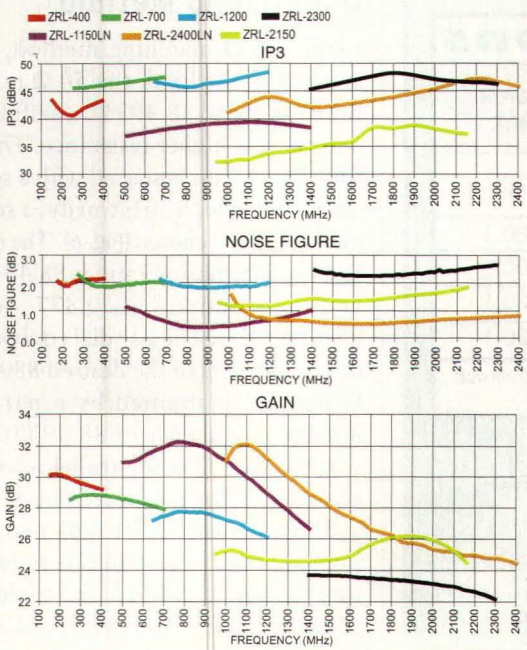

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$$L_1 = \frac{25.667\ \Omega}{6.28\ \Omega / nH} = 4.09\ nH \qquad (23)$$

The series equivalent circuit on the right has the required 10.43-Ω real part, and, because the circuit Q is unchanged, a +j20.32-ohm reactive part. However, a +7.238-Ω reactance is required, so part of this reactance must be tuned out using a series capacitor C_2. The reactance magnitude of C_2 is 20.32 – 7.24 = 13.08 Ω. This is provided by a capacitor, C_2 with the value

$$C_2 = \frac{159}{13.08} = 12.16\ pF \qquad (24)$$

The resulting circuit and performance are shown in **Fig. 5**.

With input tuning, the gain, S_{21}, is about 18.4 dB at 1 GHz, compared with about 15.9 dB for the stabilized (but untuned) transistor alone (from Part 2), a gain improvement of 2.5 dB. This is consistent with the result to be expected in tuning the 2.5 dB mismatch loss of the stabilized transistor, having an S_{11} magnitude of 0.661 (Table 1). Keep in mind that this S_{21} is the gain of the overall two-port network in Fig. 5.

Also from Table 1, $|S_{22}|$ = 0.414. This means that 17 percent of the power is being lost due to the output mismatch. If this were recovered, the gain could increase by another 0.8 dB. To tune the output port, the output impedance at 1 GHz is seen from **Table 2** to be (88.493 – j46.646) Ω. The 50-Ω load is to be transformed to the complex conjugate of this value or

$$Z_L = (88.493 + j46.646)\ \Omega \qquad (25)$$

Q Matching Method

Using the Q matching method, and starting at the load, the 50 Ω is first transformed to 88.493 Ω, a shift from a lower to a higher resistance. Therefore, the process is started with a series circuit for which, arbitrarily, a series inductor, L_2, is chosen **(Fig. 6)**. The resistive transformation ratio is 88.493/50 and the required Q is 0.877, hence L_2 is 6.99 nH. The parallel equivalent circuit consists of the desired 88.493-Ω resistance shunted by a parallel inductive reactance of 88.493/0.877 = 100.86 Ω. This is parallel resonated at 1 GHz by a capacitance, C_2, of 1.576 pF. An additional reactive impedance of +j46.646 Ω is required to transform the 50-Ω load to the Z_L given in Eq. 22, and this is achieved with a series inductor, L_3, of 7.43 nH. The stabilized 2N6977A amplifier with unilaterally tuned input and out-

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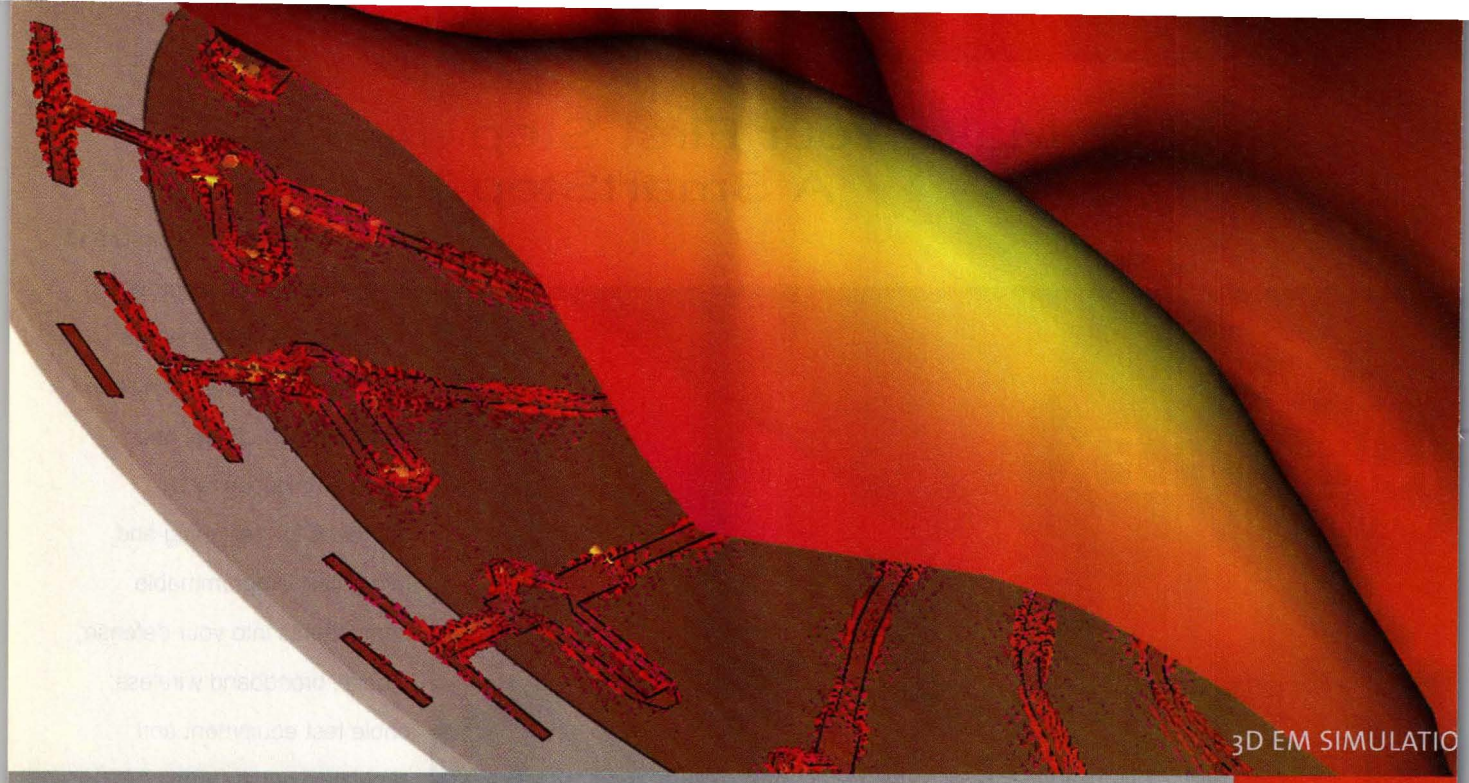

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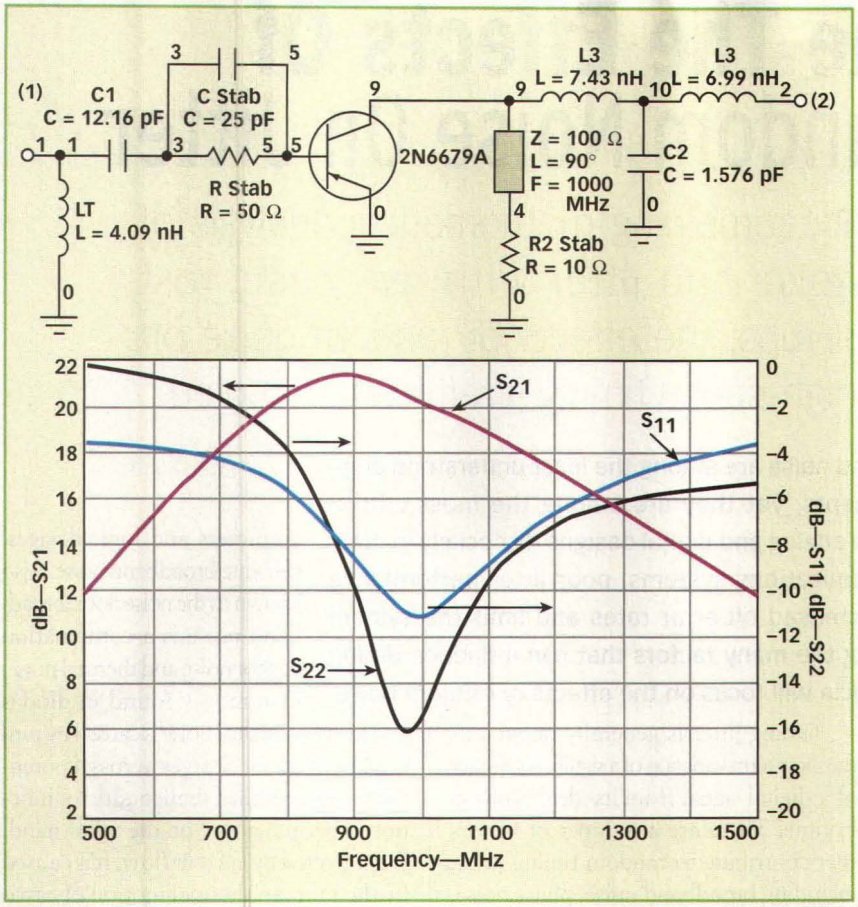

6. This plot shows the performance for the 2N6679A transistor amplifier stabilized and unilaterally input and output tuned.

put is shown in Fig. 5 along with its performance.

The gain when both input and output are matched is 20 dB at 1 GHz. This is within 1 dB of the 19.2 dB maximum gain expected. Recall that the unilateral figure of merit analysis indicated that the error in gain estimate could be between –1.18 dB and +1.37 dB. The 20-dB gain is an increase over the input-matched case (Fig. 4) of 1.6 dB. This is more than the 0.8 dB expected improvement. Also, both the input and output are imperfectly matched as can be seen from the plots of S_{11} and S_{22} in Fig. 5. These inaccuracies are to be expected in the unilateral gain method, when the transistor's internal feedback, S_{12}, is ignored.

For optimum performance, it is possible to find a source and load impedance pair that perfectly matches the transistor at any given frequency. This approach—the simultaneous conjugate match—will be covered next month in Part 4 of this continuing article series. MRF

About The Author

Joseph White is a consultant and instructor. He received the Ph.D. EE degree from Rensselear Polytechnic Institute and has over 25 years of engineering experience. He published the textbook *High Frequency Techniques* (John Wiley & Sons, 2004) and teaches a one week industrial course, *Wireless Engineering*, from which these articles are excerpted.

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Examine The Effects Of Random Noise On Jitter

By combining mathematical analysis of noise and jitter with two basic test setups, the effects of random noise on high-speed timing jitter can be studied.

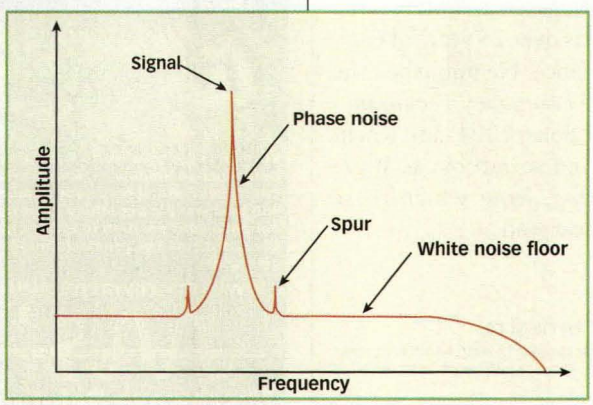
KEN YANG
Senior Member of the Technical Staff
STEVE LEE
Member of the Technical Staff
Maxim Integrated Products, 120 San Gabriel Dr., Sunnyvale, CA 94086; (408) 737-7600, FAX: (408) 737-7194, e-mail: ken_yang@maximhq.com, e-mail: steve_lee@maximhq.com, Internet: www.maxim-ic.com.

Timing jitter and noise are among the least understood engineering concepts, yet they are among the most critical parameters in analog and digital designs. Especially in high-speed communications systems, poor jitter performance can cause increased bit-error rates and limit the system speed. Among the many factors that can influence timing jitter, this article will focus on the effects of random noise.

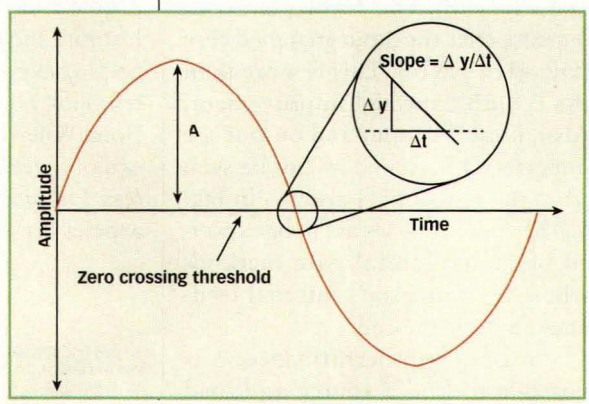
Timing jitter is generally defined as the short-term variation of a significant instant of a digital signal from its ideal position in time. There are a number of factors that contribute to random timing jitter, including broadband noise, phase noise, spurious signals, slew rate, and bandwidth. Both phase and broadband noise are random, whereas spurious signals are deterministic responses caused by various identifiable interference signals, such as crosstalk and power supply coupling. Slew rate and bandwidth also affect jitter. **Figure 1** shows a nonideal sinusoid that contains the three noise sources; in a digital clock signal, these sources contribute to jitter that accumulates over time.

All electronic components, especially amplifiers and logic devices, generate broadband noise. Also known as the noise floor, broadband noise is a combination of shot noise and thermal noise. Commonly found in diodes and transistors, shot noise is caused by random hopping of charges across a potential barrier within a semiconductor junction. Thermal noise, on the other hand, is unaffected by current flow. It is caused by the random thermal motion of carriers, for example within a MOSFET's gate and channel resistance. The thermal noise power is directly proportional to the resistance and temperature.

The effect of broadband noise on timing jitter becomes significant as the operating bandwidth of modern components pushes into the multi-GHz range. For example, a broadband amplifier driver with 40-GHz bandwidth, 10-dB noise figure, 20-dB small-signal gain, and 0-dBm output power generates a –38-

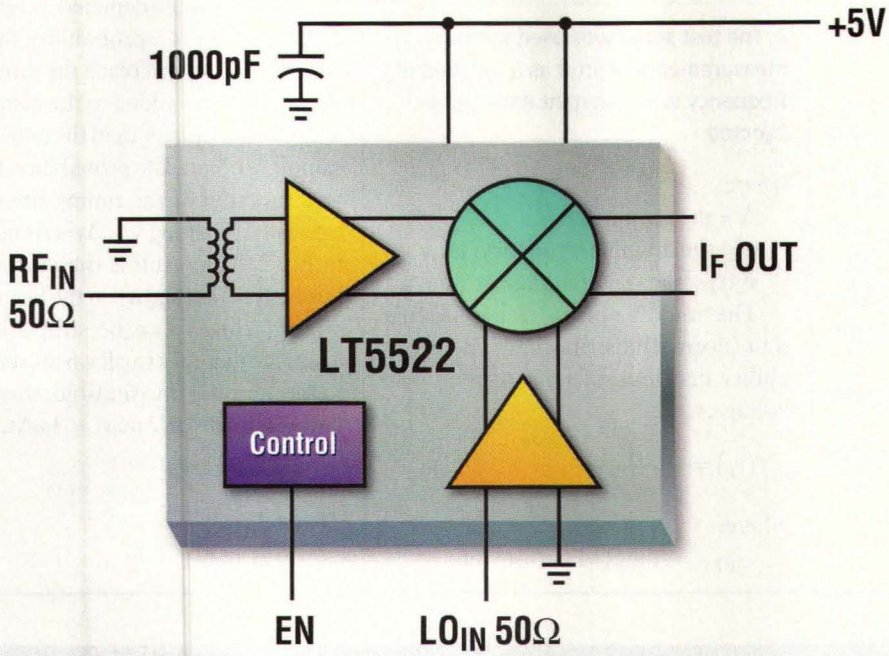


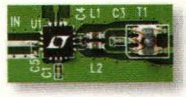
1. Three random noise sources contribute to timing jitter in high-speed signals.



2. Noise voltage Δy at the 0-V crossing causes the signal to reach threshold Δt earlier than the ideal time, causing jitter.

High Linearity, Low LO Drive





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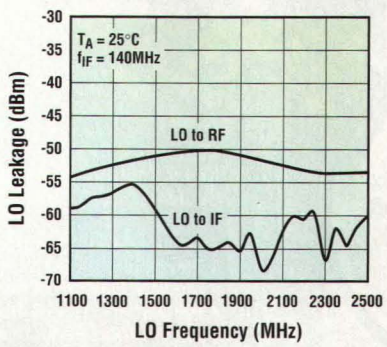
LO Leakage vs LO Frequency



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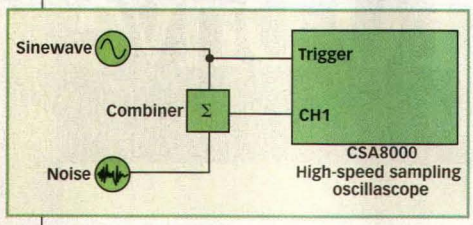
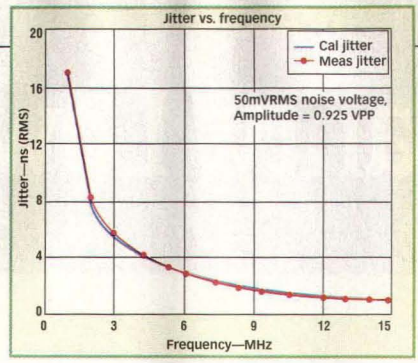


3. This jitter test setup allows the operator to control the amount of noise added to a clean signal.



4. The test setup was used to make measurements of jitter as a function of frequency with constant RMS noise injected.

dBm noise output [–174 dBm + 10 dB + 20 dB + $10\log_{10}$(40 GHz)]. This results in a signal-to-noise ratio (SNR) of 38 dB. At this SNR level, the broadband noise is a significant contributor to timing jitter. The total root-mean-square (RMS) noise voltage is the integral of the noise floor over the bandwidth.

Figure 2 illustrates how RMS noise is translated into timing jitter.

A sinusoid containing broadband white noise can be represented by:

$$y(t) = A\sin(\omega t) + v_n(t) \qquad (1)$$

where:

A = the amplitude,

ω = the angular frequency, and

$v_n(t)$ = the noise voltage at time t.

The random noise $v_n(t)$ has a Gaussian (normal) distribution. The probability distribution $f(v_n)$ of the noise voltage v_n is:

$$f(v_n) = \frac{1}{\sqrt{2\pi v_{nRMS}^2}} e^{-\frac{v_n^2}{2v_{nRMS}^2}} \qquad (2)$$

where:

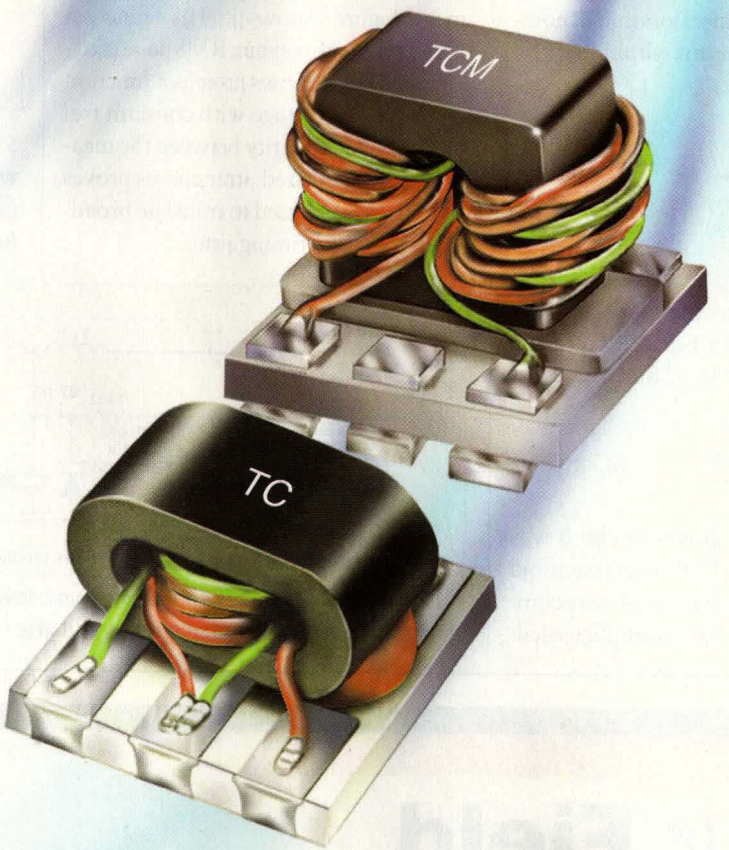
v_{nRMS} = the RMS noise voltage.

To understand how noise voltage is translated into timing jitter, consider applying y(t) into the input of a jitter-measuring instrument, such as a sampling oscilloscope with a histogram function. Each time y(t) crosses the 0-V threshold, a data point is added to the histogram. Just as depicted in Fig. 2, at time Δt, there is a probability that the noisy signal Δy will reach the threshold; thus the jitter is added to the histogram at Δt sooner or later than the anticipated sampling point. The probability density as a function of the timing jitter Δt is calculated by setting $v_n = \Delta y = A\sin(2\pi f\Delta t)$ in Eq. 2. The result is the jitter distribution function shown in the histogram.

Equation 3 can be simplified by assuming that Δt is small when compared to the period of the sinusoid; therefore, $A\sin(2\pi f\Delta t) \cong A(2\pi\Delta t) = A\omega\Delta t$:

$$f(\Delta t) = \frac{1}{\sqrt{2\pi v_{nRMS}^2}} e^{-\frac{[A\sin(2\pi f\Delta t)]^2}{2v_{nRMS}^2}} \qquad (3)$$

RF TRANSFORMERS



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TCM3-1T	3A	2-500	5-300	1.09
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TCM4-19	4H	10-1900	30-700	1.09
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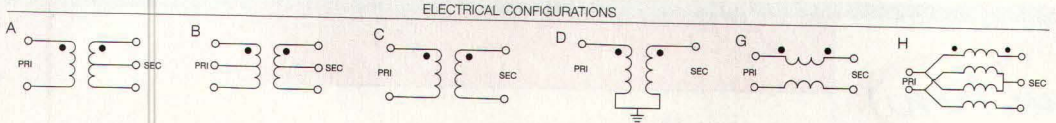

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Equation 3 then becomes:

$$f(\Delta t) = \frac{1}{\sqrt{2\pi v_{nRMS}^2}} e^{-\frac{(A\omega\Delta t)^2}{2 v_{nRMS}^2}} \quad (4)$$

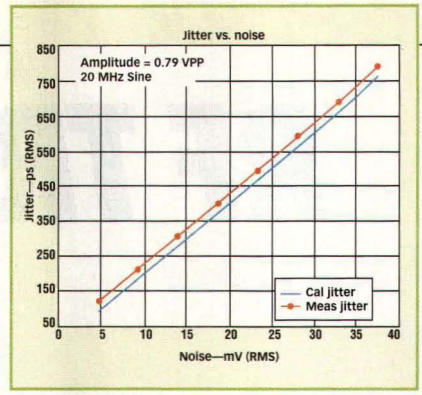
Dividing the numerators and denominators of various terms within Eq. 4 by Aω yields:

$$f(\Delta t) = \frac{1}{A\omega} \frac{1}{\sqrt{2\pi \frac{v_{nRMS}^2}{(A\omega)^2}}} e^{-\frac{(\Delta t)^2}{2\frac{v_{nRMS}^2}{(A\omega)^2}}} \quad (5)$$

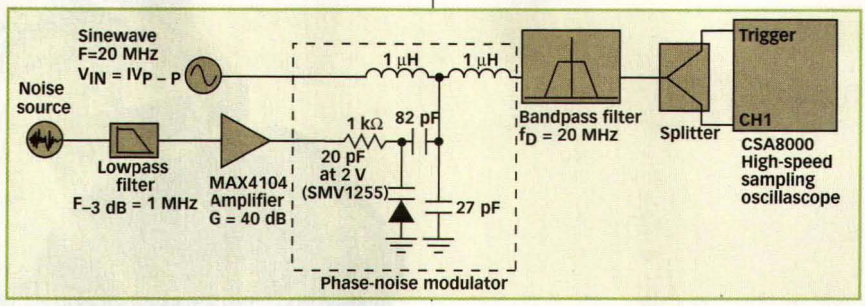
Equation 5 is a jitter distribution function similar to the Gaussian distribution shown in Eq. 2, except for the scale factor 1/Aω. Thus, the RMS jitter is found as:

$$Jitter_{RMS} = \frac{V_{nRMS}}{A\omega} \quad (6)$$

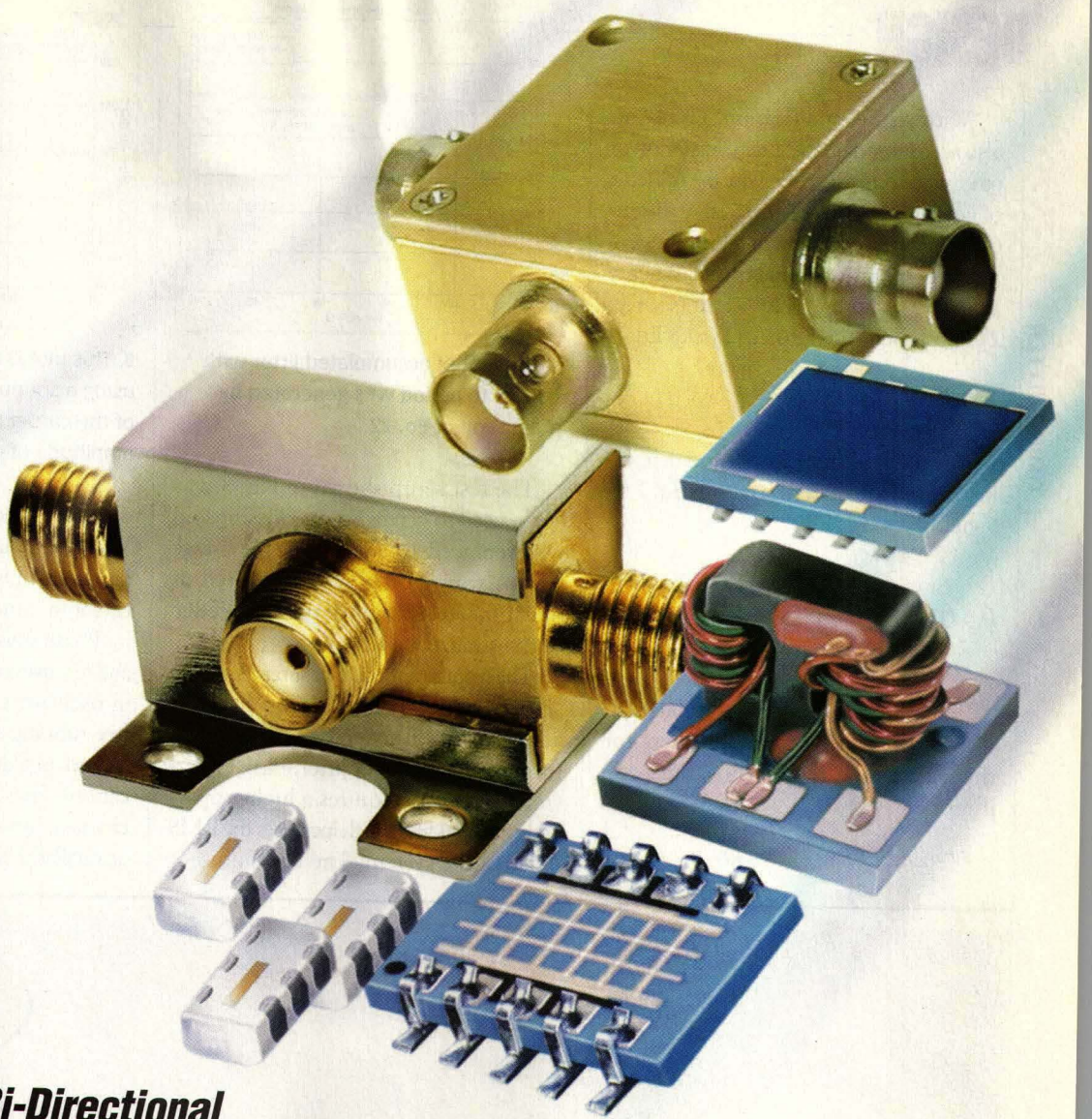
The test setup shown in **Fig. 3** was used to verify Eq. 6. Both a clean sinusoid and a broadband noise signal were combined and injected into a sampling oscilloscope where jitter was measured at the zero crossing. To ensure meaningful results, the input broadband noise was set higher than the noise floor of the oscilloscope. **Figures 4 and 5** show the results of the experiment. Figure 4 shows jitter as a function of frequency with constant RMS noise injected, while Fig. 5 shows jitter as a function of RMS noise voltage with constant frequency. The similarity between the measured and calculated jitter curves proves that Eq. 6 can be used to translate broadband noise into timing jitter.



5. These measurements were made with the first test set at a constant frequency of 20 MHz showing jitter as a function of RMS noise voltage.



6. This second jitter test setup employs a low-noise phase modulator to generate controlled amounts of phase noise and jitter.



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With slight modification, Eq. 6 can also accommodate the jitter translation of other waveforms. By definition, the Aω term of Eq. 6 is the slew rate S at the 0-V threshold. Any waveforms with a known slew rate at the threshold can be used to relate Δt to Δy, because $v_n = \Delta y = S\,\Delta t$ (see Fig. 2). Substituting this into Eq. 2 yields Eq. 7:

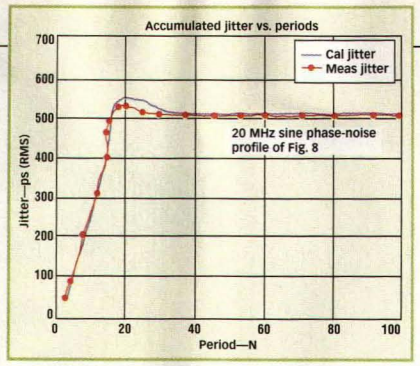
$$f(\Delta t) = \frac{1}{\sqrt{2\,\pi\,v_{nRMS}^2}} e^{-\frac{(S\,\Delta t)^2}{2\,v_{nRMS}^2}} \qquad (7)$$

Dividing the numerators and denominators of various terms within Eq. 7 by S yields:

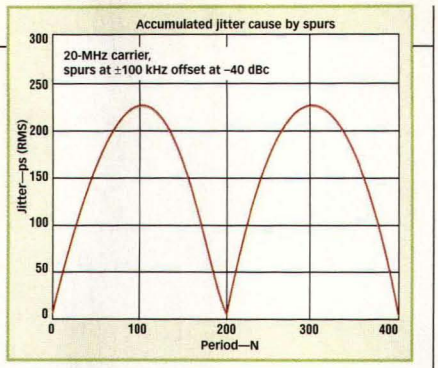
$$f(\Delta t) = \frac{1}{S} \frac{1}{\sqrt{2\,\pi\,\frac{v_{nRMS}^2}{S^2}}} e^{-\frac{(\Delta t)^2}{2\frac{v_{nRMS}^2}{S^2}}} \qquad (8)$$

Equation 8 is similar to the Gaussian distribution shown in Eq. 2 except for the scale factor of 1/S. Thus, the RMS jitter is:

$$Jitter_{RMS} = \frac{v_{nRMS}}{S} \qquad (9)$$



7. This plot of accumulated jitter with respect to period was generated by integration of Eq. 22.



8. This plot is a visualization of Eq. 23 using a spurious product on both sides of the carrier at 100 kHz offset and an amplitude of –40 dBc.

The test setup shown in Fig. 3 was again used to verify Eq. 9. The sinusoid was replaced by a variable-slew-rate square wave. Jitter was measured at the 50-percent point of the rising edge of the square wave.

The results of those measurements (not shown) raise an interesting point. It appears that a faster slew rate waveform results in lower jitter. However, a faster slew rate requires a higher operating bandwidth, which increases the RMS noise of the system. The RMS noise is directly proportional to the bandwidth. With this relationship in mind, system designers must carefully choose the slew rate and bandwidth to minimize jitter.

Phase noise is present in every active and resistive component, but it is most severe in oscillators. These oscillators include free-running crystal oscillators and phase-locked oscillators in clock-recovery applications. Phase noise is a specification that characterizes spectral purity. For example, an oscillator output should ideally be a pure

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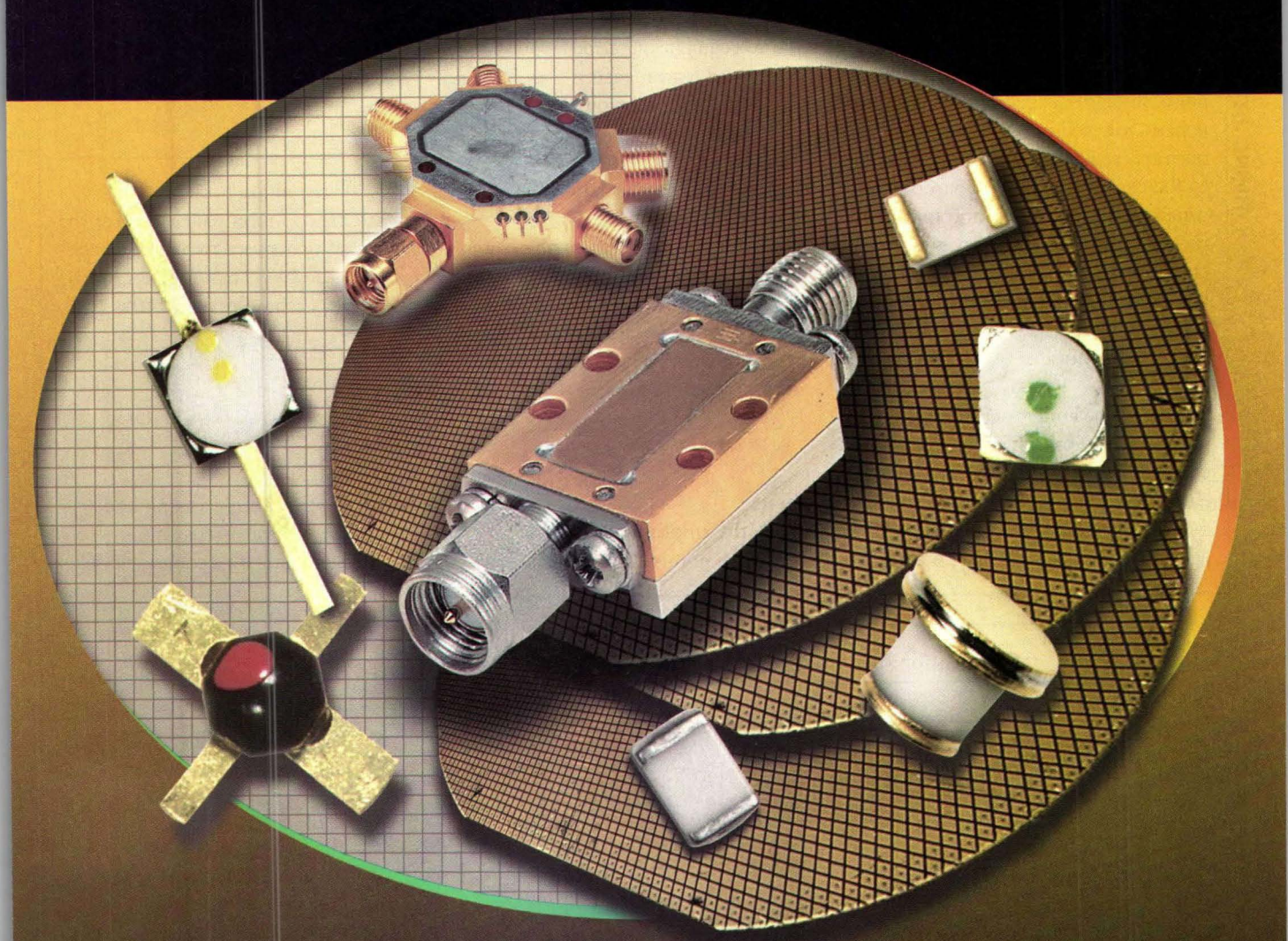

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sinusoid represented as a vertical line, stationed on a single frequency, in the frequency domain. However, in reality, there are noise sources in the oscillator that can cause the output frequency to deviate from its ideal position, thus generating a "skirt" of other frequencies near the carrier (fundamental) frequency. Referred to as phase noise, these frequencies result from the noise sources modulating the oscillator. They often appear above the noise floor and close to the carrier frequency. Phase noise is usually specified as the ratio of a noise power at an offset frequency away from the carrier to the carrier power, in a 1-Hz bandwidth. Because noise sources frequency-modulate the signal to produce phase noise, phase noise is unaffected by the slew rate.

Due to the limitations of most jitter-measuring equipment, it is often easier to characterize the purity of a low noise signal by measuring its phase noise in the frequency domain rather than measuring jitter in the time domain. For example, most jitter-measuring oscilloscopes are only capable of measuring jitters down to 1 ps RMS. Most modern real-time oscilloscopes only have bandwidths to 7 GHz. Phase-noise test equipment, on the other hand, can measure noise levels of the best low-noise oscillators available (much less than 1 ps in the time domain) and offer bandwidths of to 40 GHz.

The translation between phase noise and timing jitter has been explored in previous articles.[1,2] To derive the necessary equations relating phase noise to jitter, consider Eq. 10 as a sinusoid containing phase noise:

$$V(t) = A\ \sin\left(2\pi f_O t + \phi(t)\right) \quad (10)$$

where:

A = the amplitude,

f_o = the nominal frequency, and

$$2\pi\frac{1}{T_o}\left(NT_o + \Delta t\right) + \phi(t_2) - \phi(t_1) = 2\pi N \quad (15)$$

$$\Delta t = \frac{T_o}{2\pi}\left(\phi(t_1) - \phi(t_2)\right) \quad (16)$$

$$\left\langle \Delta t^2 \right\rangle = \frac{T_o^2}{4\pi^2}\left(\left\langle \phi(t_1)^2 \right\rangle - 2\left\langle \phi(t_1)\phi(t_2) \right\rangle + \left\langle \phi(t_2)^2 \right\rangle\right) \quad (17)$$

$$\left(\left\langle \phi(t_1)^2 \right\rangle = \left\langle \phi(t_2)^2 \right\rangle\right) = \int_{-\infty}^{\infty} S_\phi(f)df \quad (18)$$

$$\left\langle \phi(t_1)\phi(t_2) \right\rangle = R_\phi(t_2 - t_1) = R_\phi(\tau) = \int_{-\infty}^{\infty} S_\phi(f)\cos(2\pi\tau)df \quad (19)$$

$\phi(t)$ = the phase noise.

Jitter is commonly measured at the 0-V crossing between two or more periods. At the 0-V crossing, the terms inside the parentheses of Eq. 10 is $2\pi N$,

$$2\pi f_o t_1 + \phi(t_1) = 0 \quad (11)$$

$$2\pi f_o t_2 + \phi(t_2) = 2\pi N \quad (12)$$

where:

t_1 = the first zero-crossing and

t_2 = the Nth zero-crossing.

Subtracting the two equations yields

$$2\pi f_o(t_2 - t_1) + \phi(t_2) - \phi(t_1) = 2\pi N \quad (13)$$

The time between the two zero-crossings is the number of periods plus the jitter

$$t_2 - t_1 = NT_o + \Delta t \quad (14)$$

where:

T_0 = the period or $1/f_0$ and

Δt = the jitter accumulated after N periods.

Substituting Eq. 14 into Eq. 13 yields Eq. 15. Rearranging Eq. 15 and cancelling out the $2\pi N$ terms yields jitter, Eq. 16. The squared RMS jitter is given by Eq. 17. Because $\phi(t)$ is a stationary process, Eq. 18 results.

where:

$S_\phi(f)$ = the spectral density of $\phi(f)$ and

f = the offset (Fourier) frequency.

The middle term of Eq. 17 then becomes Eq. 19, where:

$R_\phi(\tau)$ = the autocorrelation function of $\phi(f)$ and $\tau \cong NT_o$ = the time after the Nth period.

The squared RMS jitter after the Nth period at time τ can be calculated by Eq. 20.

Recalling the algebraic identity $1 - \cos(2\pi f\tau) = 2\sin^2(\pi f\tau)$ and assuming the

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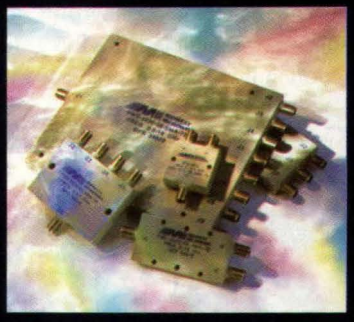

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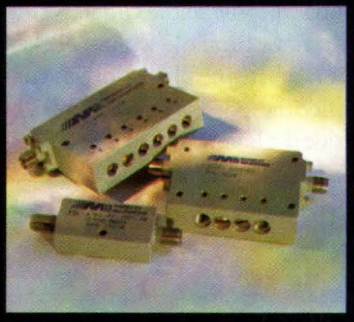

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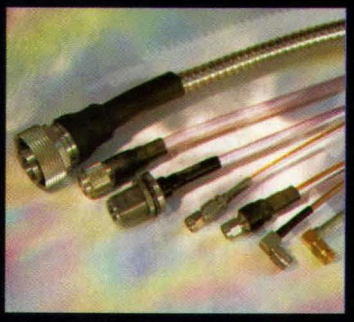

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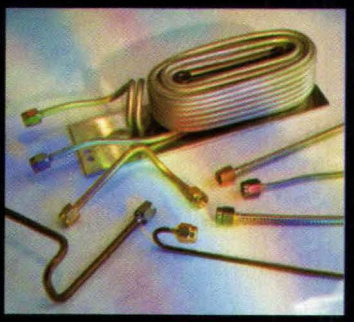

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$$\Delta t^2_{RMS}(\tau) = 2\frac{T_o^2}{4\pi^2}\int_{-\infty}^{\infty} S_\phi(f)\left(1-\cos(2\pi\tau)\right)df \quad (20)$$

$$\Delta t^2_{RMS}(\tau) = 8\frac{T_o^2}{4\pi^2}\int_{0}^{f_{OFFSET}} S_\phi(f)\left(\sin^2(\pi f\tau)\right)df \quad (21)$$

$$Jitter^2_{RMS}(\tau) = 8\frac{T_o^2}{4\pi^2}\int_{0}^{f_{OFFSET}} L(f)\left(\sin^2(\pi f\tau)\right)df \quad (22)$$

$$Jitter^2_{RMS}(\tau) = 4\frac{T_o^2}{4\pi^2}\sum_n L(f_n)\sin^2(\pi f_n\tau) \quad (23)$$

$$Jitter^2_{Total} = Jitter^2_{Noise\_Floor} + Jitter^2_{Phase\_Noise} + Jitter^2_{Spur} \quad (24)$$

phase noise is close to the carrier and symmetrical, meaning the integration from $-f_{OFFSET}$ to 0 equals the integration from 0 to $+f_{OFFSET}$, Eq. 20 can be rewritten as Eq. 21.

Term $S_\phi(f)$ is approximately equal to the phase noise $L(f)$ for close-in phase noise[3]; that is, the Fourier offset frequency is much less than the carrier frequency: $f_{OFFSET} << f_O$ and Eq. 22 results.

A phase-modulating circuit[4] was used as part of the test setup shown in **Fig. 6** to verify Eq. 22. The phase-modulating circuit provides a convenient way to produce a variable phase-noise signal that is free of spurious content. The output of the circuit was first measured for timing jitter with a sampling oscilloscope, and then measured for phase noise with a spectrum analyzer (not shown). The phase-noise profile of the circuit is similar to the noise profile of a phase-locked oscillator, where the phase noise is constant inside the loop bandwidth and rolls off outside the bandwidth. Using numerical integration to integrate Eq. 22, the resulting accumulated-jitter with respect to period was plotted in **Fig. 8**, which confirms the validity of Eq. 22.

Spurious signals also contribute to timing jitter, especially in oscillators. Spurious signals are caused by phase-locked-loop (PLL) reference spurious products, power-supply coupling, crosstalk from nearby circuitry, and other sources. As shown in Fig. 1, these spurious products usually appear as small spikes near the carrier frequency. Equation 22 can help relate spurious signals to timing jitter. Because spurious signals only occur at specific frequencies, the integration function in Eq. 22 can be replaced with Eq. 23.

Since Eq. 23 does not assume that the spurs are symmetrical, it is multiplied by a factor of 4 instead of 8. The spurious products on both sides of the carrier must be included in the jitter calculation. $L(f_n)$ is the spurious amplitude relative to the carrier (the desired signal) and is usually given in dBc. Parameter f_n is the offset frequency of the nth spurious product. **Figure 9** shows the plot of Eq. 23 using a spurious product on both sides of the carrier at 100 kHz offset and an amplitude of –40 dBc. Reference 1 verifies Eq. 23 by modulating a voltage-controlled crystal oscillator with a sinusoid to produce a spurious product on each side of the carrier (not shown).

Broadband noise, phase noise, and spurious products are the three contributors to timing jitter. Broadband noise is purely random and uncorrelated, thus the jitter it produces does not accumulate. The latter two, however, generally do produce accumulating jitter. The squared total timing jitter is the sum of the three squared jitters. The noise-floor jitter term is calculated from Eq. 9, the phase-noise jitter term is calculated from Eq. 22, and the spur jitter term of Eq. 24 can be calculated from Eq. 23.

The correlation between the experimental and calculated data demonstrates the relationship between the three major noise sources and timing jitter. Designers of high-speed systems can use Eqs. 9, 22, and 23 to translate noise into timing jitter. MRF

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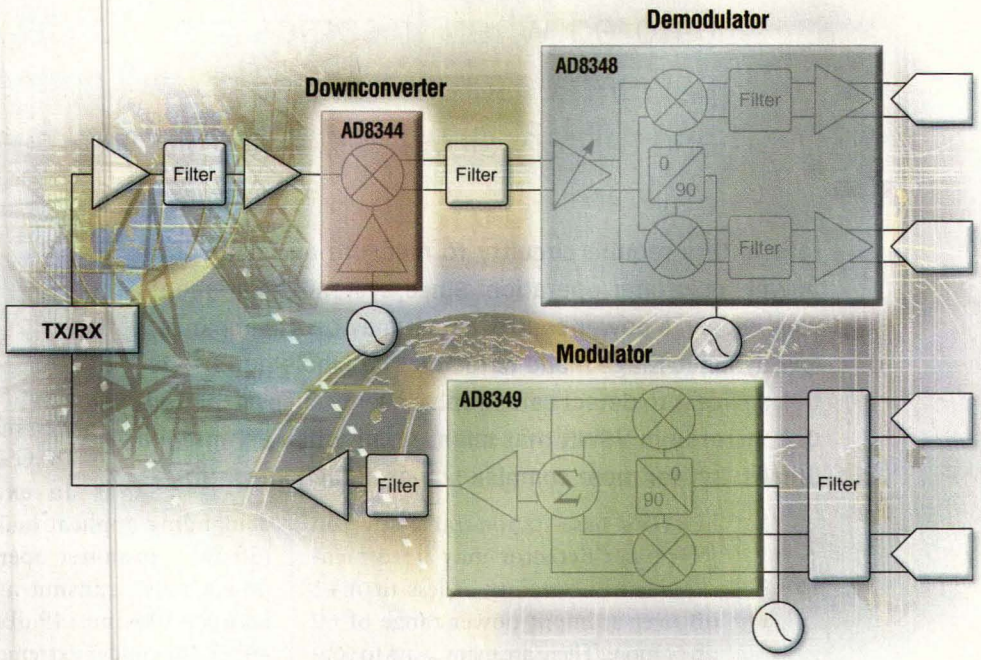

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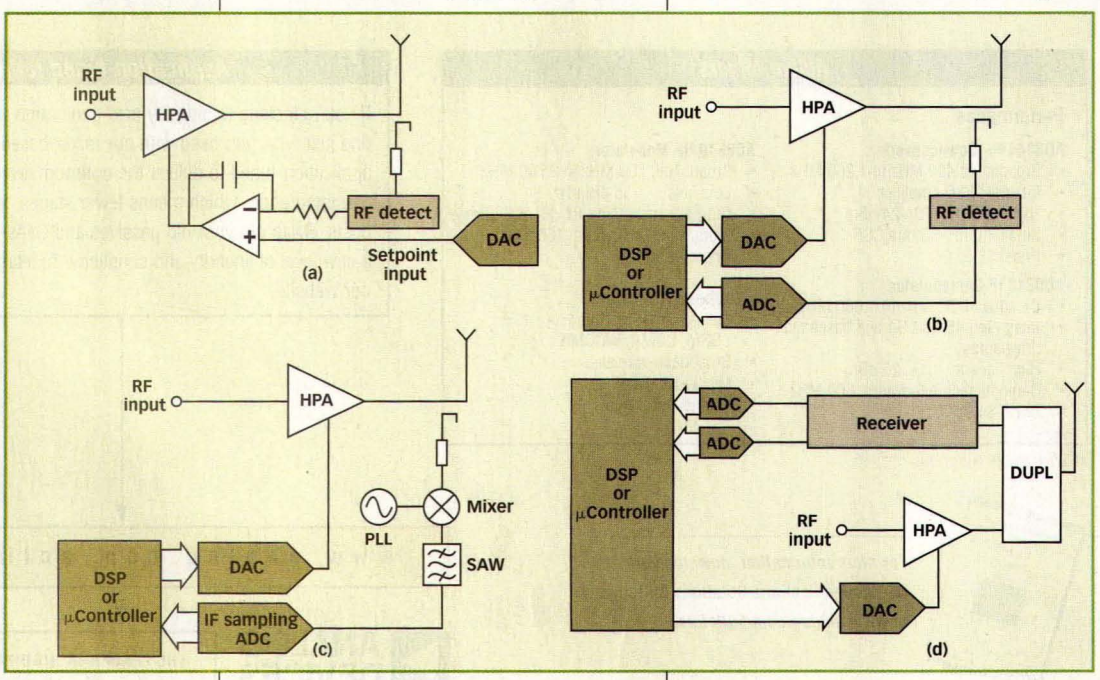
Transmitters require circuitry to measure and control RF power for proper operation. Since system requirements vary widely, a power-control circuit may be as simple as a low-dynamic-range diode detector. The whole purpose for this device is to detect catastrophic events such as the sudden increase in VSWR that might occur when an antenna breaks. But for more complex power detection control, as in a GSM base-station transmitter, an RF power detector may need measurement uncertainty of less than ±1 dB over an input power range of 60 dB or more. There are many ways to control RF power, but ever-improving logarithmic-amplifier (logamp) technology offers many solutions.

The GSM transmitter is an example of a demanding application. A +47-dBm (50-W) transmitter operating at full power must transmit a power level between +45 and +49 dBm[1] (+44.5 to +49.5 dBm under extreme conditions). To stabilize the output level, the amplitude of the transmitter's input signals



1. Fast measurement and control of RF power is achieved using an analog control loop (a). A slower loop with digital control involves sampling the detector output and adjusting output power with a DAC (b). An auxiliary IF sampling receiver includes power-measurement capability (c). By measuring received power the correct transmitted power can be estimated (d).

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VLF-5000	DC-5000	5580	6600	19.95
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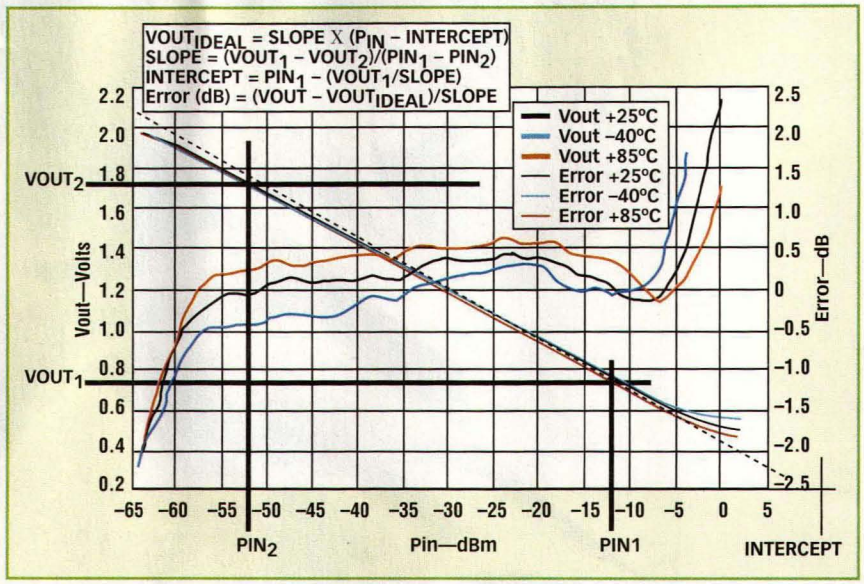
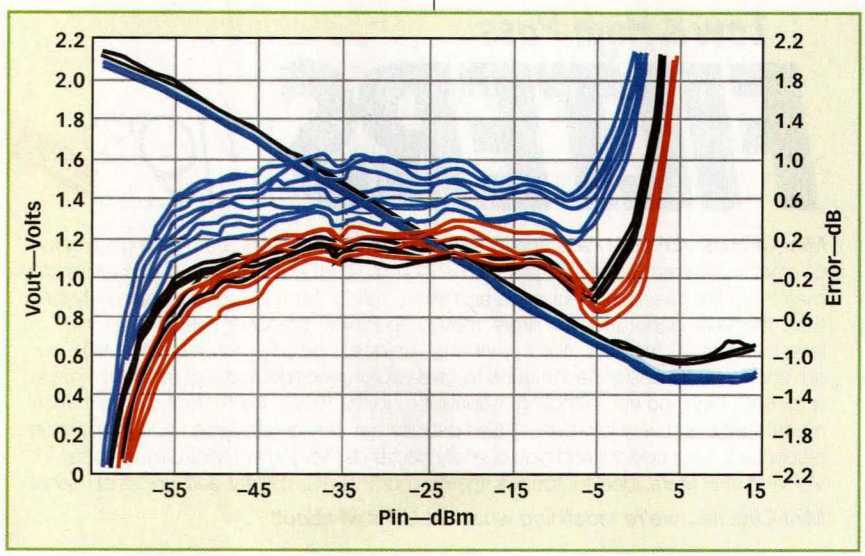


2. This plot shows the transfer function of the AD8318 logamp at 2.2 GHz. The slope and intercept are calculated by applying two input signal levels and measuring the resulting output voltage.

must be precisely known, often within ±1 dB over a wide dynamic range.

There are a number of ways to measure this power, including the use of a closed-loop architecture **(Fig. 1a)**. In this approach, a directional coupler (with typically 10 to 30 dB coupling) is used to sample power from the power amplifier (PA) to the antenna. Some additional attenuation is generally necessary to reduce the power within the safe measurement range of the detector. This measured result is compared to a set-point voltage; the difference drives an integrator (also commonly referred to as an error amplifier).

The error amplifier's output will rise or fall until the output power of the PA corresponds to the set-point voltage. The error amplifier will not necessarily drive the bias control of the PA; the system will be just as effective if the PA has fixed gain and the error amplifier is used to control the gain of an



3. Overlaying data from multiple devices, measured at 5.8 GHz in this case, gives a good indicator the worst-case temperature drift that can be expected. Temperature drift of the population is optimized at a particular frequency using an external compensation resistor.

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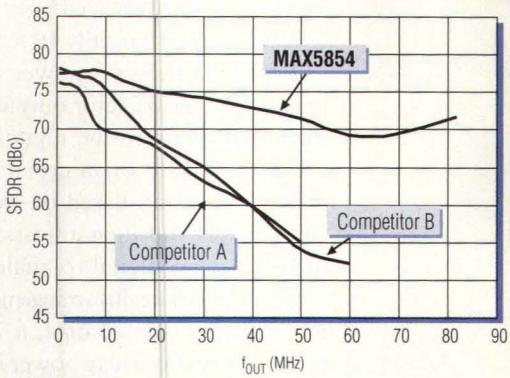

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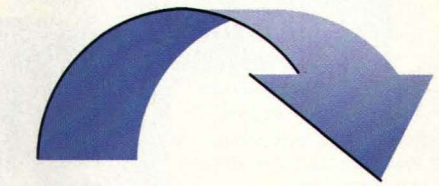

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intermediate-frequency (IF) variable-gain amplifier (VGA).

This type of power control (known as controller mode from the perspective of the detector) is useful in systems requiring fast control of power, such as time-division-multiple-access (TDMA) systems where power is transmitted in precisely timed bursts. The fast "local" control allows the power to be ramped up and down in a controlled fashion. If a logarithmic detector is used, the power can be controlled over a large dynamic range (typically 40 to 60 dB).

Figure 1b shows a power control loop where the detector output is digitized. Software in the digital signal processor (DSP) or microcontroller makes a decision based on the measured result and then adjusts output power using a digital-to-analog converter (DAC). Since this arrangement does not allow for fast control, it is more useful in systems where power is transmitted continuously, such as CDMA, WCDMA, and TD-SCDMA systems. With digital control, extra calibration can be added to the measurement loop. For example, if the power detector drifts (but with good repeatability) with temperature, a compensation algorithm can be implemented if the system contains a temperature sensor.

Figure 1c shows a wireless transmitter with an *auxiliary receiver* in which the signal being transmitted is sampled and mixed back down to baseband. The use of an auxiliary receiver is common in HPA linearization schemes such as *feedforward* and *digital pre-distortion*, where it provides feedback to the algorithm about the quality of the transmitted spectrum. In this implementation, measurement of transmitted power comes for free. The measurement will be accurate as long as the gain of the receiver does not vary significantly with temperature or frequency.

Figure 1d shows alternative power control architecture used in some handsets. The architecture assumes that the transmitted power should be determined based on the received power. For example, if the received power is decreasing, the transmitted power should

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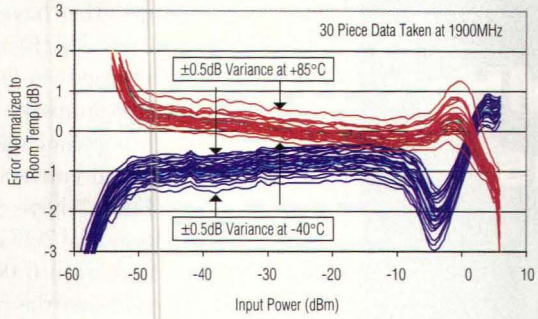

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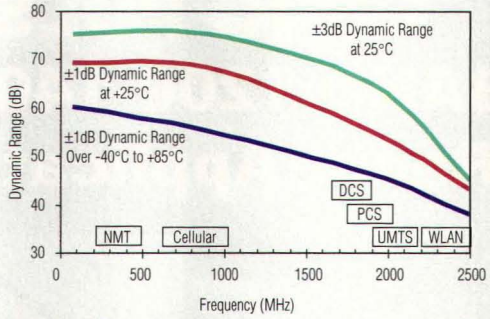

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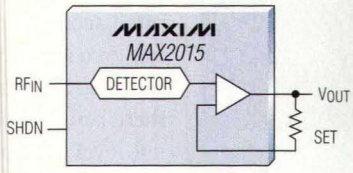

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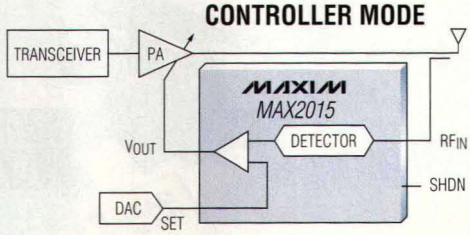

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be increased. This is a slow and somewhat imprecise system. However, it is a useful way to set power during the initiation of a link.

In general, power-measurement accuracy is most critical when the PA is at, or close to, full power. For example, in a +50-dBm (100-W) transmitter, a –1-dB error in the voltage from the power measurement circuit will result in a transmitted power of +51 dBm (126 W). This forces the PA to be overdimensioned by 25 percent (making it physically larger and more expensive) to guarantee safe operation. However, at low power levels, the tolerance of the output power is only required to be within the limits of the wireless standard.

The temperature stability of the detector in these applications is critical. Traditionally, diodes have been used to perform this function. While diode detectors have good temperature stability when driven hard (good performance is generally achieved at input powers in the +15 dBm range), they have limited dynamic range (20 to 30 dB) and drift severely at low input power levels.

Demodulating logamps are becoming an increasingly popular choice when systems call for measurement and control of RF power. **Figure 2** shows the transfer function of a logamp at 2.2 GHz. The AD8318, specified from 0.001 to 8 GHz, was used to generate this plot. The figure shows output voltage and calculated error, both versus input power.

As the input power varies from –65 to 0 dBm, the output voltage varies from 2 V to about 0.5 V.

Calibration is required to achieve the rated accuracy of a log detector. This is true even if the detector is factory trimmed. Looking again at Fig. 1, we can see that there can be uncertainty about the signal level reaching the logamp. Signal trace losses, and part-to-part variability in the coupling factor of the directional coupler and attenuator can easily produce 1 dB or more of uncertainty.

The recommended method of calibration is to set the PA output to two or more approximate levels and measure the detector's output voltage.

Within its linear operating range, a logamp with approximately follow the equation:

$$V_{OUT} = SLOPE(P_{IN} - INTERCEPT) \quad (1)$$

Slope is the incremental change in output voltage for a corresponding change in input power (unit is mV/dB). The *intercept* is the point (in dBm or dBV) at which the extrapolated linear transfer function touches the x-axis.

In general, the calibration is performed by applying two power levels (one at the top end of the input range and one at the bottom end) and measuring the

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Gali 51F	DC-4000	18.0	15.9	3.5	32	78	50	4.4	1.29
Gali 5F	DC-4000	20.4	15.7	3.5	31.5	103	50	4.3	1.29
Gali 55	DC-4000	21.9	15.0	3.3	28.5	100	50	4.3	1.29
Gali 52	DC-2000	22.9	15.5	2.7	32	85	50	4.4	1.29
Gali 6	DC-4000	12.2	18.2	4.5	35.5	93	70	5.0	1.49
Gali 4	DC-4000	14.4	17.5	4.0	34	93	65	4.6	1.49
Gali 51	DC-4000	18.1	18.0	3.5	35	78	65	4.5	1.49
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corresponding output voltages from the detector. Calculation of slope and intercept is done using the Eqs. 2 and 3.

Once SLOPE and INTERCEPT have been calculated, Eq. 4 can be written which will allow calculation of an (unknown) input power based on the output voltage of the detector.

$$SLOPE = \left(V_{OUT1} - V_{OUT2}\right) / \left(P_{IN1} - P_{IN2}\right) \quad (2)$$

$$INTERCEPT = P_{IN1} - V_{OUT1} / SLOPE \quad (3)$$

$$P_{IN}\left(unknown\right) = V_{OUT}\left(measured\right) / SLOPE + INTERCEPT \quad (4)$$

$$Error\left(dB\right) = \left(V_{OUT\,MEASURED} - V_{OUT\,IDEAL}\right) / SLOPE \quad (5)$$

Using the ideal equation for output voltage (Eq. 1) as a reference, the log conformance error of the measured data can be calculated with Eq. 5.

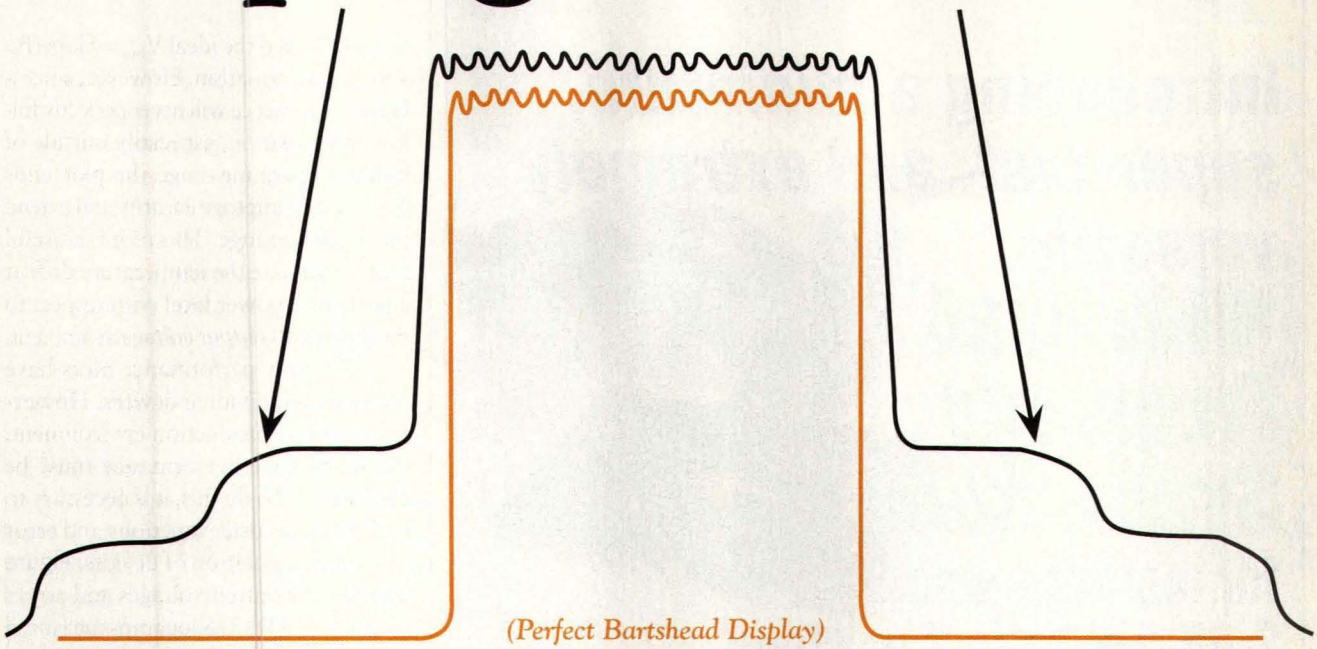
Figure 2 includes a plot of the error at +25°C, the temperature at which the logamp is calibrated. Note that the error is not zero. This is because the logamp does not perfectly follow the ideal V_{out} versus P_{in} equation, even within its operating region. The error at the calibration points (–12 and –52 dBm in this case), however, will be equal to zero by definition.

Figure 2 also includes error plots for the output voltage at –40 and +85°C. These error plots are calculated using the SLOPE and INTERCEPT at +25°C. This is consistent with calibration in a mass-production environment where calibration over temperature is not practical.

It is possible to improve narrowband performance at higher power levels by changing the calibration points (data not shown), although the error functions will change. The shape of these error functions will vary as the calibration points are changed. Using calibration points of –10 and –30 dBm, for example, results in an error of 0 dB at +25°C at these calibration points. In the range between the calibration points, the errors at ambient temperature and over all operating temperatures are very small. At lower power levels from –30 to –60 dBm, however, the error degrades. This calibration scenario might be used in a transmitter where precision is most critical near full power. In general, the calibration points should be selected at the boundaries of the range over which the highest precision is desired.

Calibration points should therefore be chosen to suit the application at hand. In general, though, the calibration points should never be chosen in

Danger. Sloping Shoulders.



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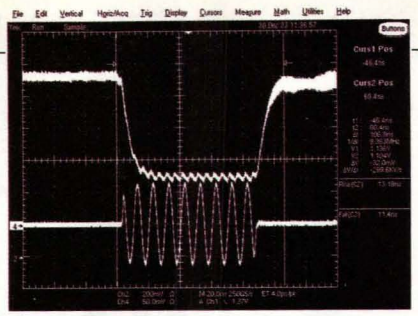
the nonlinear portion of the logamp's transfer function (above –5 dBm or below –55 dBm in this case).

The error function of a logamp detector can also be analyzed in terms of the dB error values at various temperatures with respect to the *output voltage* at ambient temperature. Until now, errors have been plotted with respect to the *ideal transfer function* at ambient temperature. Using this alternative technique, the error at ambient becomes equal to 0 by definition. This would be valid if the device transfer function perfectly followed the ideal V_{out} = Slope(P_{in} – Intercept) equation. However, since a logamp in practice will never perfectly follow this equation, especially outside of its linear operating range, this plot tends to artificially improve linearity and extend the dynamic range. This plot is a useful tool to estimate the temperature drift at a particular power level with respect to the (nonideal) *output voltage* at ambient.



4. This plot shows the envelope response of AD8318 to a 90-ns-wide, 100-MHz RF burst. The attack time is 11.4 ns while the decay time is 13.2 ns.

Until now, performance plots have focused on individual devices. However, in a mass-production environment, the worst-case performance must be considered. To do this, it is necessary to look at the transfer functions and error plots of a population of devices. **Figure 3** shows the output voltages and errors of multiple AD8318 logamps measured at 5.8 GHz. The concentration of black plots represent the performance of the population at +25°C (the slope and intercept has been calculated for each device). The red and blue plots of error indicate the measured behavior of a large population of devices over temperature. This suggests a range on the drift (from device-to-device) of 1.2 dB with worst-case drift at –40°C. If operation to –10°C or even –20°C is desired, the temperature drift will be much smaller.

The AD8318 functionality includes the capability to externally trim the temperature drift. Attaching a ground-referenced resistor to the T_{ADJ} pin alters an internal current that works to stabilize intercept drift versus temperature. As a result, the T_{ADJ} resistor can be optimized for operation at different frequencies. While the T_{ADJ} resistor could be chosen on a device-by-device basis, this is not practical since each logamp would have to be characterized for temperature drift. In practice, the population information supplied in Fig. 3 can be

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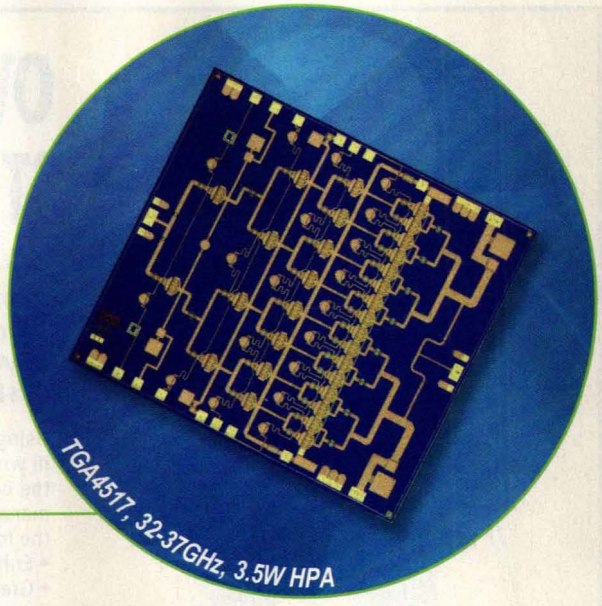

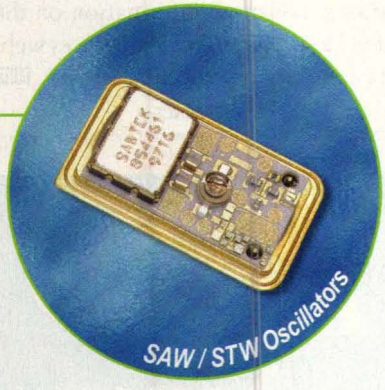

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used to choose the value of T_{ADJ} resistor that will yield the best overall drift.

In time-division multiplexed applications, the RF detector must be able to quickly respond to large-signal changes at the input. In a controller mode application (Fig. 1a), the detector must have a response time (the term video bandwidth is commonly used) that is fast enough so that the dominant pole of the control loop is set by the capacitor of the integrator.

Figure 4 shows the output of the AD8318 in response to a short RF burst. Because the slope of the logamp is negative, the output falls after the onset of the burst with a 90-to-10-percent fall time of 11.4 ns. This response time is more than adequate for almost all power measurement applications. This extremely fast response time also opens up more application possibilities such as radar receivers or amplitude-shift-keying (ASK) detection.

The ripple in the response of the detector, at twice the input frequency, is a by-product of the logarithmic transformation. Because of the high video bandwidth of the logamp, these artifacts will be present when the input signal is at a relatively low frequency. A lowpass filter can easily eliminate this ripple, but this will come at the expense of some response time. At high input frequencies (greater than 100 MHz), the internal video bandwidth will remove all ripple.

Logamp detectors that can accept input frequencies up to 8 GHz are beginning to replace the more traditional diode detectors. Out-of-the-box temperature stability is much better than ±1 dB and holds up over a large dynamic range. Response time is fast enough for use in radar and ASK-detection applications. For more information on the AD8313, visit the Analog Devices website at www.analog.com/AD8313. MRF

REFERENCE

1. GSM Standard for Radio Transmission and Reception ETSI TS 100 910 V8.9.0 (2001-04), page 14.

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Parameter	Min	Typ	Max	Unit	Notes
Frequency of Operation	0.1		2.3	GHz	
Small Signal Gain	25	26		DB	
VSWR In/Out		1.35/1	1/4/1		
Isolation (S12)	35	40		DB	
Pout 1db Comp.	9	10		DBm	
Noise Figure		1.2	1.3	DB	
DC Current @ +5Vdc		120	140	mA	
Unit-To-Unit					
Gain Tracking	-1		+1	DB	Set or 2 units or more
Phase Tracking	-1		+1	Degrees	Set of 2 units or more
Package Size					1.21" x 0.67" x 0.37 SMA-connectorized

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Guidelines For Selecting An Oscilloscope

OSCILLOSCOPES ARE WORKHORSE test instruments for electrical engineers, whether their circuitry of choice is analog, digital, RF, or microwave. Because so many competitive high-speed oscilloscopes are currently available, and comparing specifications among different manufacturers can be confusion, many engineers may be listed in the 10-step plan offered in a 14-page application note from Agilent Technologies, "Ten Things to Consider When Selecting Your Next Oscilloscope."

In brief, the 10 things to consider when selecting an oscilloscope are how much bandwidth is needed, how many channels are needed, what is the sample rate requirement, how much memory is needed, what kind of display capabilities are needed, what triggering capabilities are needed, what is the best way to probe a signal, what documentation and connectivity are needed, how will waveforms be analyzed, how important is ease of use.

As the note points out, bandwidth is the most important characteristic of an oscilloscope, since it determines the range of signals to be displayed and to an extent, the price that will be paid for the instrument. When making a decision on bandwidth, consideration should be given to budget limitations in context with the expected measurement needs over the operating lifetime of the oscilloscope. For example, current measurement requirements may reach as high as 2.5 GHz, but future projects may operate at frequencies beyond 5 GHz, in which case an oscilloscope under consideration should greatly exceed the current requirements. Also, the influence of harmonic signals must be considered (which can greatly extend the required bandwidth), especially when evaluating such components as amplifiers where harmonic distortion plays a large part in the overall performance of the amplifier.

The 14-page application note (Application Note 1490) is available from free download from the company's website. It clearly covers each of the 10 specification areas with simple formulas that can be applied to a "grocery list" when shopping for a new oscilloscope.

Agilent Technologies, Inc., 395 Page Mill Rd., Palo Alto, CA 94306; (877) 424-4536, FAX: (650) 752-5300, Internet: www.agilent.com.

Bandwidth is the most important characteristic of an oscilloscope, since it determines the range of signals to be displayed and, to an extent, the price that will be paid for the instrument.

Evaluate WiMAX For Last-Mile BWA

INTERNET USERS can never get enough speed in their connections. For this reason, they are willing to pay healthy fees for broadband Internet access, especially if it comes with the convenience of broadband wireless access (BWA). To address the use of the Worldwide Interoperability for Microwave Access (WiMAX) standard for BWA use, Fujitsu Microelectronics America (Sunnyvale, CA) has made available an informative 10-page white paper, "WiMAX Technology and Deployment for Last-Mile Wireless Broadband and Backhaul Applications."

The WiMAX standard supports a wide variety of WiMAX-based products, including different configurations of base stations and customer premise equipment (CPE). The standard supports a wide range of wireless broadband connections, including high-bandwidth metropolitan-area networks (MANs) to home and small-business users, replacing cable modems operating on cable-television (CATV) networks and digital-subscriber-line (DSL) connections on wired-pair telephone lines; backhaul networks for cellular base stations, bypassing the public-switched telephone network; and backhaul connections to the Internet for wireless-local-area-network (WLAN) hotspots.

The WiMAX protocol is presented as fairly secure, and designed for high quality of service (QoS). For example, the protocol's grant-request mechanism is geared to prevent large numbers of users from interfering with one another and allow for high utilization of available channel resources. The network does not slow down even when thousands of users are operating simultaneously. The white paper details the protocol's MAC and PHY layers and includes a block diagram for a typical WiMAX subscriber station. Copies of the note can be downloaded for free from the company's website, or by using the link www.fma.fujitsu.com/WPBWA.html.

Fujitsu Microelectronics America, Inc., 1250 E. Arques Avenue, M/S 333, Sunnyvale, CA 94088-3470; (408) 737-5600, FAX: (408) 737-5999, Internet: www.fma.fujitsu.com

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LFCN-120	DC-120	195	270	7	3.99
LFCN-225	DC-225	350	460	7	2.99
LFCN-320	DC-320	460	560	7	2.99
LFCN-400	DC-400	560	660	7	2.99
LFCN-490	DC-490	650	780	7	2.99
LFCN-530	DC-530	700	820	7	2.99
LFCN-575	DC-575	770	900	7	2.99
LFCN-630	DC-630	830	970	7	2.99
LFCN-800	DC-800	990	1400	5	1.99
LFCN-900	DC-900	1075	1275	7	1.99
LFCN-1000	DC-1000	1300	1550	7	1.99
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LFCN-1400	DC-1400	1700	1975	7	2.99
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cover story

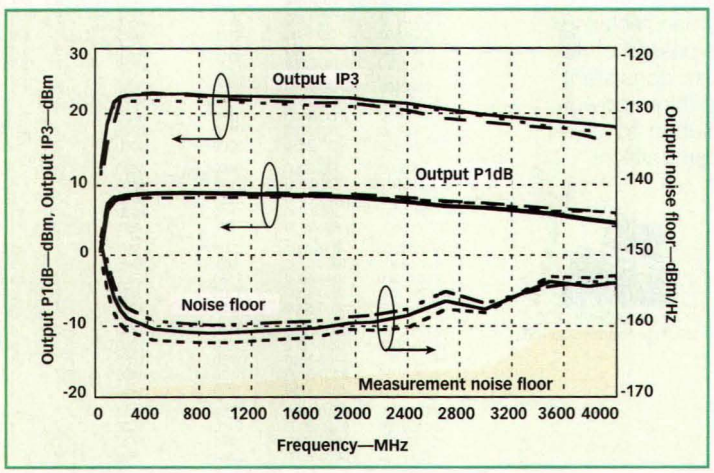
Modulators Direct Linear Gain And Phase

Broadband direct and vector modulators make the most of different semiconductor processes to provide linear, low-noise performance with precise control.

JACK BROWNE
Publisher/Editor

Modulators make wireless transmissions possible. Whether in fixed wireless links, wireless local loops (WLLs), or current and next-generation cellular systems, modulators enable the complex modulation formats that support modern, high-data-rate wireless communications. In support of a wide range of communications systems, Hittite Microwave Corp. (Chelmsford, MA) has launched both the wideband model HMC497LP4 100-to-4000-MHz direct quadrature modulator and the HMC500LP3 1800-to-2200-MHz vector modulator. The RF integrated circuits (RF ICs) offer excellent linearity with precise amplitude and phase control over temperature.

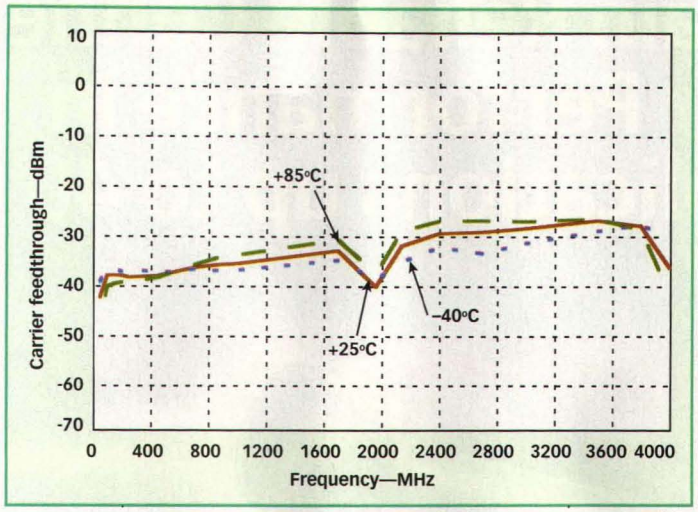
The two modulators (see front cover) differ in their process technologies as well as their functions. As a fabless semiconductor company, Hittite's engineers enjoy the freedom of matching the best semiconductor process to a given application. While exploring several options for the model HMC497LP4, several goals were set as improvements over the company's earlier model HMC495LP3 direct quadrature modulator (250 to 3800 MHz). These goals included enhanced broadband noise floor, increased output power, and better image sideband suppression. By evaluating several semiconductor processes, improving silicon- and GaAs-based technologies, the best combination of dynamic range and linearity was achieved with an advanced silicon-germanium (SiGe) process.



1. The HMC497LP4 direct quadrature modulator provides stable outputs and noise characteristics at measurement temperatures of –40, +25, and +85°C.

Supporting a wide frequency range of 100 to 4000 MHz, the HMC497LP4 employs a local-oscillator (LO) input phase splitter to feed in-phase (I) and quadrature (Q) signals to a pair of mixers which,

in turn, have their RF outputs combined in a wideband summer. The input phase splitter can be driven by wideband LO signals from 100 to 4000 MHz at levels from –6 to +6 dBm. The LO can be driven in either differential or single-ended mode. The RF output signals are available at a single-ended port matched to 50 Ω. The compact RF IC accepts wideband modulation input signals from DC to 700 MHz in support of a wide range of current wireless standards.



2. The HMC497LP4 delivers uncalibrated carrier feedthrough suppression that is stable with temperature.

End Results

The end results of careful circuit design and the benefits of the process include lower noise floor (–159 dBm/Hz) in the HMC497LP4 compared to the HMC495LP3 (–157 dBm/Hz), more output power at 1-dB compression in the HMC497LP4 (+9 dBm) compared to the HMC495LP3 (+1 dBm), and improved sideband suppression in the new modulator (–42 dBc for the HMC497LP4) compared to the older device (–36 dBc in the HMC495LP3). In fact, the combination of the HMC497LP4's low noise floor and high output power result in an outstanding dynamic range of 168 dB at 1960 MHz and 161 dB at 3500 MHz, currently high-water marks for a direct quadrature modulator. The modulator is well suited for use in software-defined radios (SDRs) where the upconversion circuitry must dynamically vary the modulator format depending upon changing requirements and operating conditions. The broadband modulator can be used for almost any analog or digital modulation format, including binary phase-

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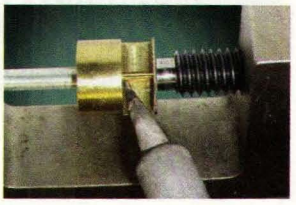

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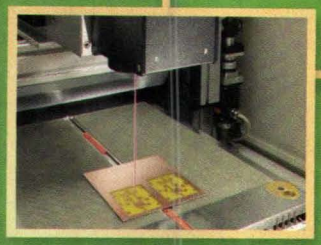
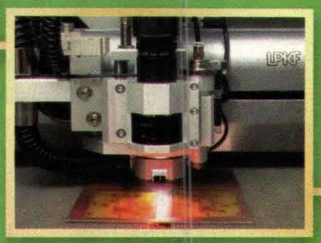


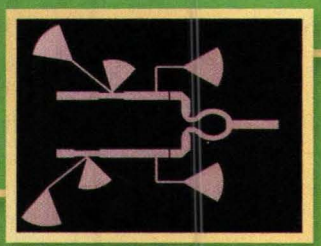
Laser Cutting Head

The system utilizes a galvo-scanner as a beam delivery system for extremely fast processing. The diode-pumped laser source is air cooled and produces short pulses minimizing heat effects.



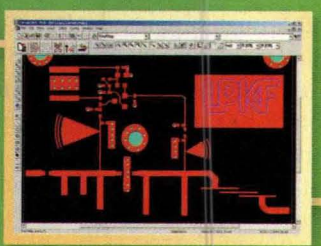
Milling Head

A precise milling head handles the drilling of holes, contour routing, and depaneling of the PWBs. Tools are changed automatically, and both the milling head and laser head have a vision system for automatic alignment.



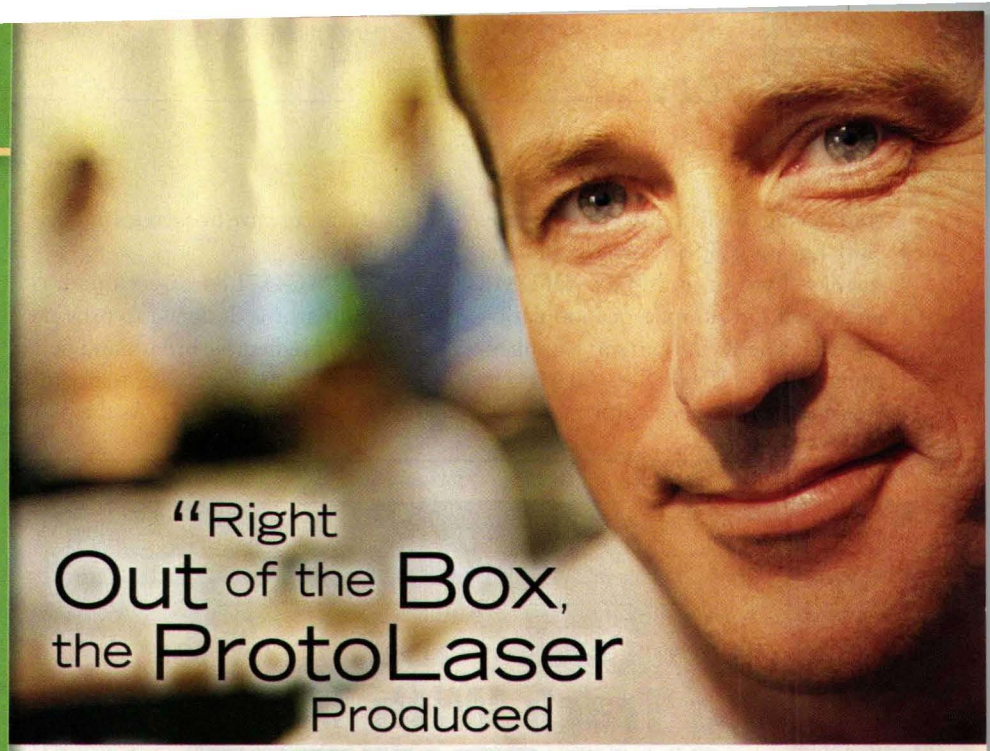
Precise Structures

An ultra-small, 1 mil (25 micron) beam produces superior artwork definition, especially in corners. The circuit shown above (2" x 1.5"), made on Rogers RT/Duroid 5880, was produced in less than 3 minutes.



CircuitCAM Software

The entire system is driven by LPKF's CircuitCAM. No third party software is needed. It is compatible with all industry standards such as Gerber, DXF, ODB++, and Excellon NC-Drill.



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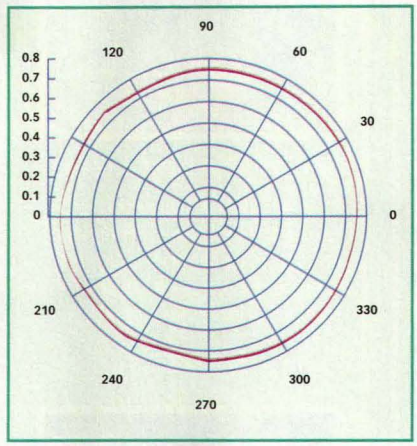
shift keying (BPSK), quadrature phase-shift keying (QPSK), orthogonal frequency-division multiplex (OFDM), and quadrature amplitude modulation (QAM). The RF IC can serve applications in the UHF band at 400 MHz as well as at RF frequencies through 2200 MHz and microwave frequencies through 4000 MHz.

The HMC497LP4 direct quadrature modulator is designed to provide stable and predictable broadband performance **(Fig. 1)** over a wide temperature range (–40 to +85°C). As the plot shows, output power remains flat across the wide frequency range, while the noise floor shows some slight rise at the higher-frequency limit, which may also be due in some part to the noise floor of the measurement equipment. The output power at 1-dB compression is +9 dBm from 1700 to 2200 MHz, +7 dBm from 2200 to 2700 MHz, and +6 dBm from 3400 to 4000 MHz, while the output noise floor is –161 dBm/Hz from 450 to 960 MHz, –159 dBm/Hz from 1700 to 2200 MHz, –157 dBm/Hz from 2200 to 2700 MHz, and –155 dBm/Hz from 3400 to 4000 MHz. Of note is the modulator's outstanding output third-order intercept point of +22 dBm from 450 to 960 MHz, +22 dBm from 1700 to 2200 MHz, +20 dBm from 2200 to 2700 MHz, and +17 dBm from 3400 to 4000 MHz.



3. The HMC500LP3 vector modulator provides 360 deg. of continuous linear phase control range.

The modulator's circuitry is configured to minimize carrier and sideband feedthrough at the RF output port. The typical uncalibrated carrier feedthrough suppression **(Fig. 2)** is –32 dBm from 450 to 960 MHz, –30 dBm from 1700 to 2200 MHz, –26 dBm from 2200 to 2700 MHz, and –24 dBm from 3400 to 4000 MHz. (With calibration, which involves manual adjustments of the I/Q port DC voltage offsets at +25°C, the measured carrier suppression shows an improvement of about 10 dB.) The typical uncalibrated sideband suppression is –43 dBc from 450 to 960 MHz, –42 dBc from 1700 to 2200 MHz, –33 dBc from

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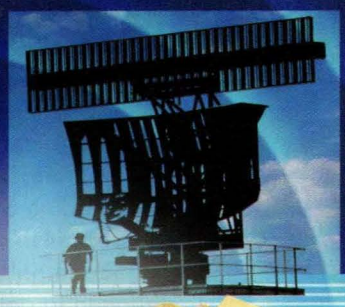
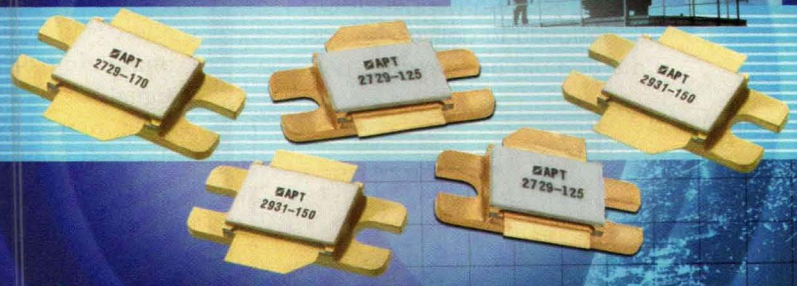


Photo courtesy of Raytheon



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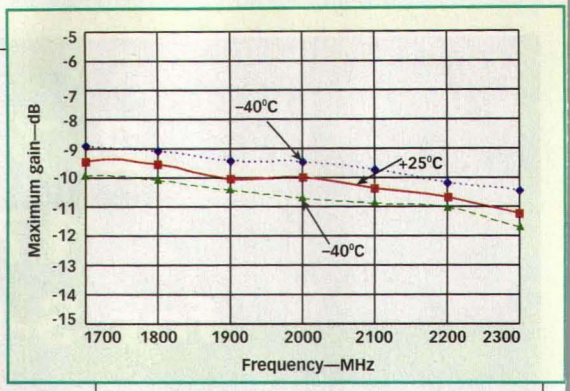
2200 to 2700 MHz, and –22 dBc from 3400 to 4000 MHz. The SiGe modulator typically requires a supply current of 168 mA at +5 VDC. The LO and RF port return loss is typically 15 dB. The direct quadrature modulator is supplied in a 4 × 4-mm QFN plastic surface-mount package.

Not to be outdone, the model HMC500LP3 vector modulator offers 360 deg. of continuous phase control from 1800 to 2200 MHz **(Fig. 3)** in combination with a typical gain control range of 40 dB. A vector modulator provides performance that is linear with respect to RF input signals compared to direct modulators which limit the input LO signal before applying the I/Q modulation signals to generate a modulated RF carrier. The vector modulator preserves the modulation already on the input RF waveform but enables additional arbitrary amplitude and phase control to be applied to the signal.



4. HMC500LP3 maximum gain over temperature.

In contrast to the direct modulator, the HMC500LP3 is fabricated with a GaAs heterojunction-bipolar-transistor (HBT) process that delivers excellent linearity from a single supply. With an input third-order intercept point of +33 dBm and input noise floor of –152 dBm at the maximum gain setting of –10 dB (the output noise floor remains flat across the full range of gain settings), the modulator boasts an input IP3/noise floor ratio of 185 dB.

The modulator –152 dB input noise floor at maximum gain is well suited for "correcting" distortion in high power amplifiers (HPAs) as part of a feedforward, predistortion, or feedbacklinearizer circuit. Digital and RF predistortion techniques attempt to correct the distortion before the input to the power amplifier. In such applications, a wide control bandwidth is critical for generating a "mirror-image" version of the distortion generated by the output amplifier. Feedback linearizers sample the output distortion and try to cancel it with sufficient loop gain. Feedforward techniques directly sample the amplifier's output distortion, amplify it, and then subtract it from the output.

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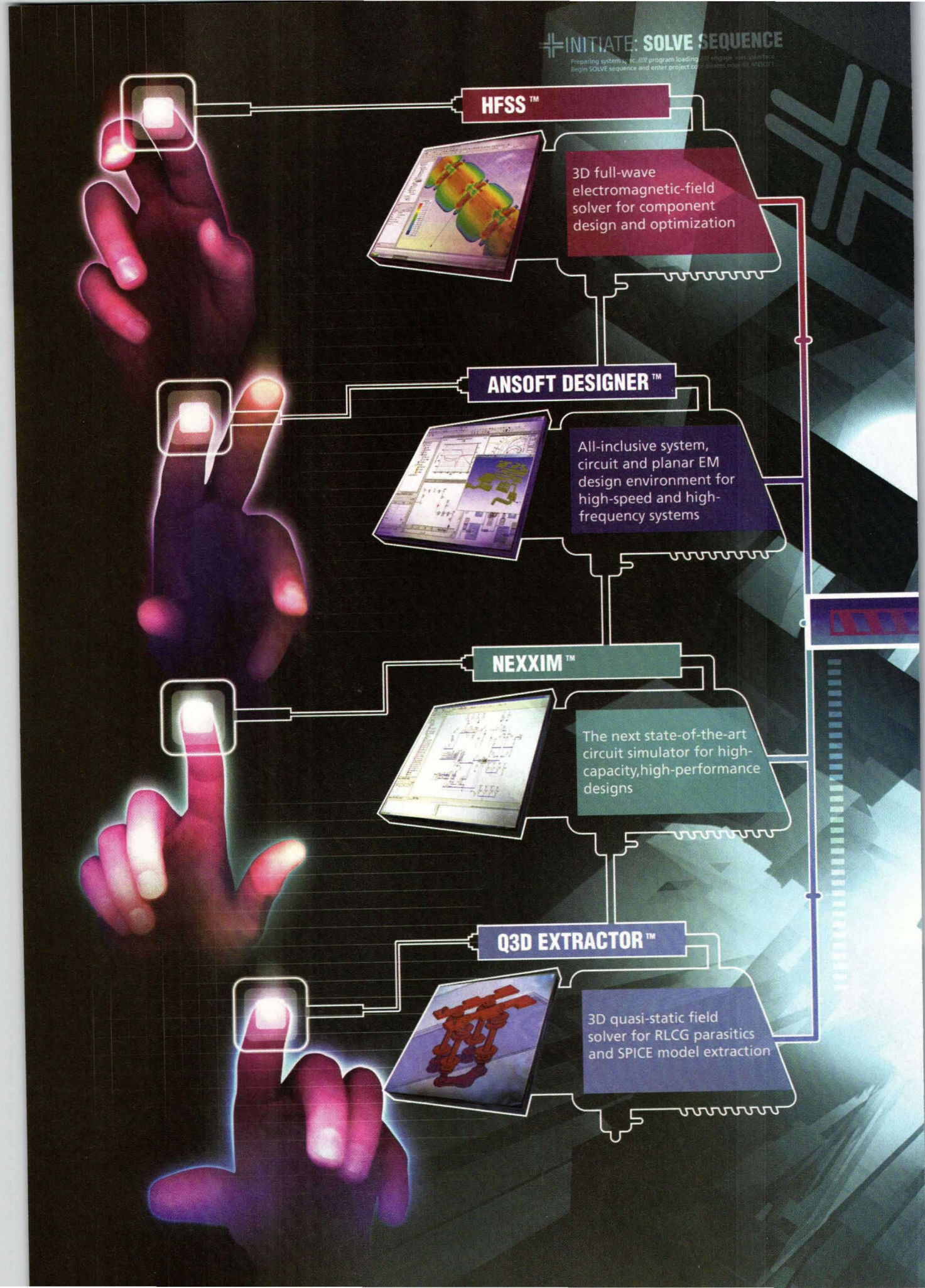
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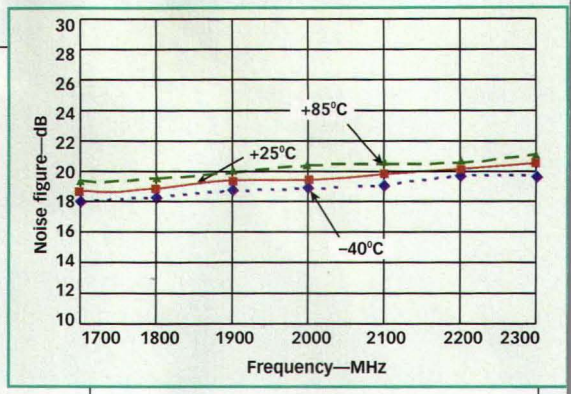
With input 1-dB compression of +16 dBm, the vector modulator can be used in phased-array systems, for analog and digital predistortion schemes, in HPA linearization circuits, and even as a limited-band electronic phase shifter. Like the direct modulator, the HMC500LP3 is designed to provide stable performance over temperature **(Figs. 4 and 5)**. It features gain flatness of 0.15 dB across any 60-MHz bandwidth and I/Q amplitude balance of ±1.5 dB. The input return loss is 17 dB while the output return loss is 15 dB. The device operates with a control voltage range of +0.5 to +2.5 VDC and exhibits control port input –3 dB bandwidth of 150 MHz with an equivalent input noise level of 6 nV/(Hz)$^{0.5}$. The vector modulator draws 90 mA at +8 VDC and is supplied in a 3 × 3-mm QFN plastic surface-mount package.



5. HMC500LP3 noise figure over temperature.

Both modulators serve wireless and other high-frequency applications with performance that is designed for stability with variations in supply current and temperature. Each has been targeted for a specific semiconductor process to achieve optimum performance while maintaining the lowest-possible power consumption. **Hittite Microwave Corp., 20 Alpha Rd.., Chelmsford, MA 01824; (978) 250-3343, FAX: (978) 250-3373, Internet: www.hittite.com.**

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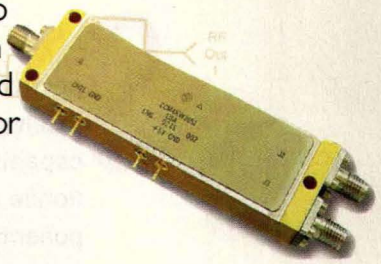
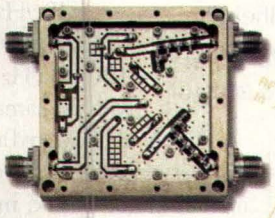
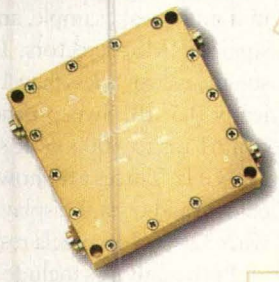
Limiting amplifier sets dynamic range from -5.0 dBm input to 2.0 dBm output. TTL controlled, fast switching and high isolation On-to-Off, and includes internal filtering for improved harmonic performance. Analog detector monitored output, or dual RF outputs.





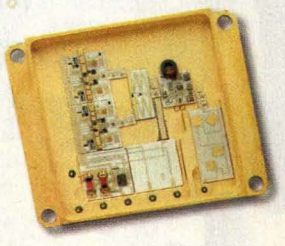


IQ Demodulator

Cougar's IQ Demodulators are fully space-qualified designs providing stringent phase and amplitude matching, and superior output third order intercept performance. To meet high LO and IF rejection requirements Cougar uses a diplexer at the I and Q ports. All components and processing fully meet MIL-PRF-38534, Class K and MIL-DTL-28837. Cougar can provide performance to meet most receiver system requirements, including single or moving LO frequencies and tight phase and amplitude matching. Customers can specify our designs for space, military, or commercial applications.

Low Noise Dual Band VCO

This custom oscillator subassembly consists of two low noise oscillators covering 1.5 to 2.5 GHz, a power combiner, a standard Cougar amplifier, and a lowpass microstrip filter. Cougar designed both oscillators for low phase noise and linear tuning. The oscillator bands are switched using standard TTL control.



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Palm-Sized Analyzer Surveys 6 GHz

These spectrum analyzers pack full-sized measurement power to 6 GHz into a handheld package that can also make power, frequency, and distance-to-fault measurements.

Spectrum analysis normally requires a heavy, rack-mount receiver with built-in filters, attenuators, and monitoring capabilities. The model FSH6 spectrum analyzer from Rohde & Schwarz (Columbia, MD) features all those components and more, but fits within a compact, handheld unit measuring just 170 × 120 × 270 mm and weighing a mere 2.5 kg. The instrument operates from 100 kHz to 6 GHz (or 100 kHz to 3 GHz as model FSH3) and includes a frequency counter with 1-Hz resolution and built-in tracking generator for scalar-analyzer measurements.

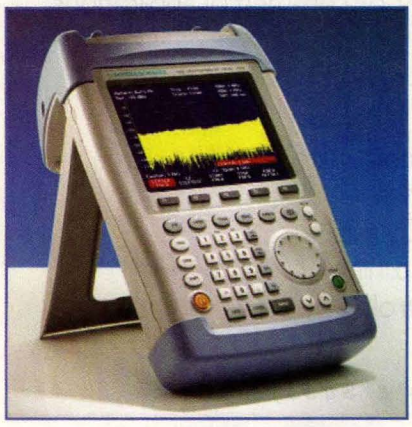
Both the 3-GHz model FSH3 and 6-GHz model FSH6 offer resolution bandwidths of 100 Hz, 300 Hz, 1 kHz, 3 kHz, 10 kHz, 30 kHz, 100 kHz, 200 kHz, 300 kHz, and 1 MHz and video bandwidths of 10 Hz to 1 MHz in a 1-3 sequence. The analyzers feature a 100-dB displayed dynamic range and amplitude reference levels can be set from –80 to +20 dBm in 1-dB steps. Sensitivity is limited only by a displayed average noise level of less than –105 dBm (typically –112 dBm) from 100 kHz to 3 GHz and less than –96 dBm through 6 GHz.

A preamplifier can be added to either analyzer to improve the noise floor to –120 dBm through 3 GHz and –105 dBm through 6 GHz. The analyzers derive their accuracy from a temperature-compensated crystal oscillator (TCXO) with 1 PPM/year aging rate and 2 PPM temperature drift from 0 to 30°C. The analyzer single-sideband (SSB) phase noise is –85 dBc/Hz offset 30 kHz from a 500-MHz carrier and –120 dBc/Hz offset 1 MHz from the same carrier.

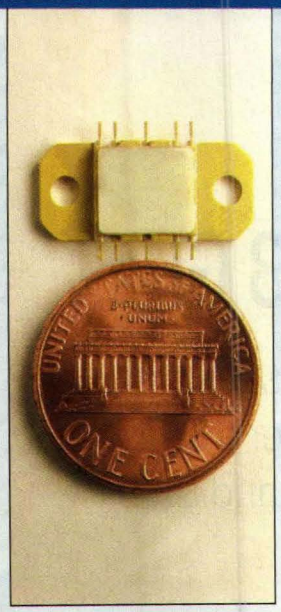
The battery-powered analyzers include a variety of detectors to capture signals, including auto peak, maximum peak, minimum peak, sample, and root-mean-square (RMS) detectors. The level measurement error is less than 1.5 dB and typically 0.5 dB. Sweep times can be set from 1 ms to 100 s over spans as wide as 6 GHz. Traces are shown on a 14-cm color liquid-crystal-display (LCD) screen with 320 × 240 pixels resolution.

Both analyzers include tracking generators for performing scalar-network-like measurements. Both analyzers are available with several options, including option FSH-K2 for distance-to-faultmeasurements over a range of 3 to 1000 m (with displays of return loss and VSWR), power sensors for measurements of levels from 200 pW to 200 mW (–67 to +23 dBm), and an RS-232C interface. **Rohde & Schwarz, Inc., 8661A Robert Fulton Dr., Columbia, MD 21046-2265; (410) 910-7800, (888) 837-8772, FAX: (410) 910-7931, e-mail: info@rsa.rohde-schwarz.com, Internet: www.rohde-schwarz.com.**

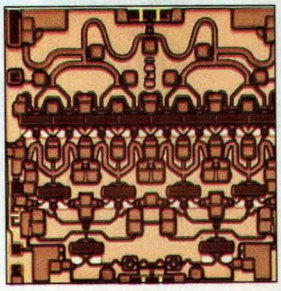
JACK BROWNE
Publisher/Editor

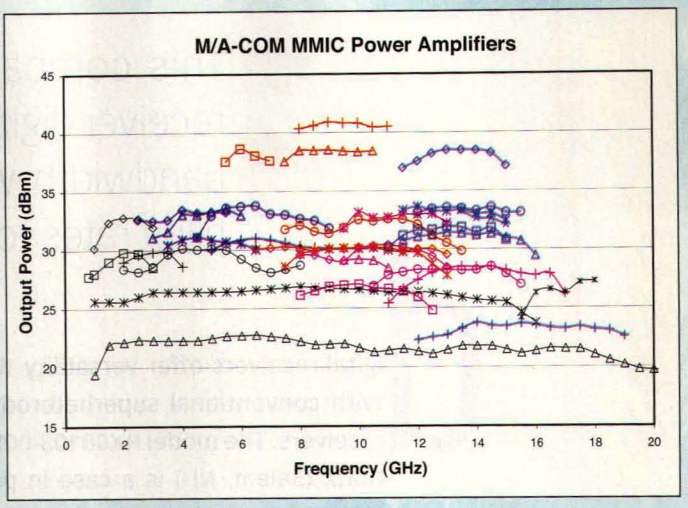


The FSH6 battery-powered spectrum analyzer packs a host of measurement solutions through 6 GHz into a package measuring just 170 × 20 × 270 mm.



Microwave and millimeter wave IC products – Power Amplifier Focus





Part Number	Frequency (gHz)	Bias (V)	PSAT (dBm)	Gain (dB)	Current (mA)
HIGH POWER AMPLIFIERS					
MAAPGM0035-DIE	2.5 - 5.5	8 / -2	32	17	850
MAAPGM0021-DIE	4.5 - 9	8 / -2	33	17	750
MAAPGM0025-DIE	5.5 - 7	8 / -2	38	17.5	2500
MAAPGM0024-DIE	7.5 - 10.5	8 / -2	38	26	2500
MA08509D	8 - 11	10 / -2	40	22	4500
MAAPGM0019-DIE	9.5 - 13	8 / -2	32	19	1200
MAAPGM0016-DIE	11.5 - 15	8 / -2	37	16	3000
MAAPGM0018-DIE	12 - 15.5	8 / -2	33	18	1200
MAAPGM0043-DIE	13.5 - 15	88 / -2	32	17	1000
MAAPGM0045-DIE	11.5 - 15	8 / -1.8	33	19	1000
MEDIUM POWER AMPLIFIERS					
MAAPGM0026-DIE	0.8 - 3.3	8 / -2	28	20	300
MAAPGM0036-DIE	1.2 - 3.2	8 / -2	31	20	700
MAAPGM0027-DIE	2 - 4	8 / -2	30	22	350
MAAPGM0028-DIE	2 - 8	8 / -2	28	14	450
MAAPGM0052-DIE	4 - 19	8 / -5	26	13	500
MAAPGM0022-DIE	3 - 6	8 / -2	31	17	900
MAAPGM0029-DIE	3.5 - 6.5	8 / -2	31	20	400
MAAPGM0030-DIE	5 - 9	8 / -2	30	17	400
MAAPGM0056-DIE	6.5 - 14	8 / -5	31	25	800
MAAPGM0051-DIE	7.5 - 13	10 / -2	31	15	400
MAAPGM0038-DIE	7.5 - 13.5	8 / -2	31	19	1100
MAAPGM0034-DIE	8.0 - 12.5	10 / -2	28	15	200
MAAPGM0039-DIE	8.0 - 13.0	8 / -2	29	15	600
MAAPGM0033-DIE	9.5 - 11.0	10 / -2	30	14	400
MAAPGM0040-DIE	10.5 - 15.5	8 / -2	27	20	250
MAAPGM0041-DIE	11.0 - 15.0	8 / -2	31	20	600
MAAPGM0042-DIE	11.5 - 16.0	8 / -2	31	20	600
MAAPGM0044-DIE	11.5 - 17.0	8 / -2	27	20	300
MAAPGM0005-DIE	12.0 - 19.0	7	23	15	200
MAAPGM0047-DIE	16.0 - 19.5	8 / -2	26	15	350
MAAPGM0046-DIE	15.5 - 18.0	8 / -1.8	26	15	350
MAAPGM0049-DIE	24.5 - 29	6 / -1.6	27	13	600
MAAPGM0012-DIE	31.5 - 36.0	5 / -1.2	17	16	200
MAAPGM0013-DIE	32.0 - 36.0	6 / -1.2	23	13	700
MAAMGM0002-DIE	1 - 18	5 / -5	21	9	100
MAAMGM0003-DIE	1 - 15	5 / -5 variable	26	7.5 (max)	480 (max)
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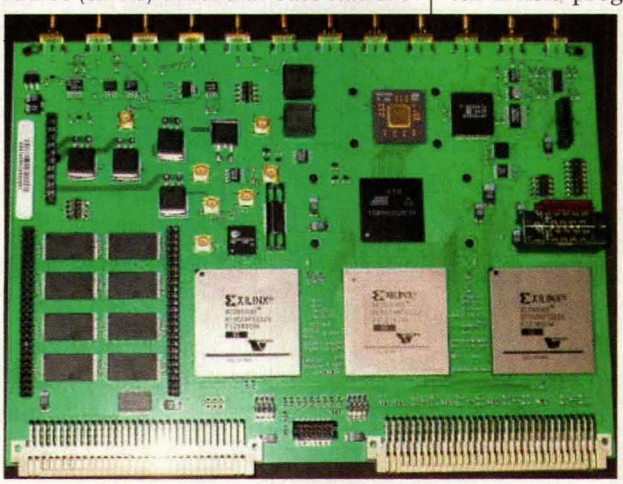
Digital Receiver Processes 3 GHz

This compact but powerful DSP-based receiver digitizes input signals over a 3-GHz bandwidth with 1-b resolution and sampling rates to 2 GSamples/s.

JACK BROWNE
Publisher/Editor

Digital receivers offer versatility that is simply not possible with conventional superheterodyne or homodyne analog receivers. The model RX00103-005 digital receiver from LNX Corp. (Salem, NH) is a case in point: the wideband, dual-channel module can capture the most transient signals from DC to 3 GHz at sampling rates to 2 GSamples/s. It makes the analog-to-digital conversion with 10-b resolution, providing 7.4 effective bits at a sampling rate of 1.4 GSamples/s for a spurious-free dynamic range of 58 dB with a 700-MHz input signal. Equipped with generous digital-signal-processing (DSP) capabilities, the compact receiver is ideal for commercial applications in the software-defined radios (SDRs) of cellular base stations and other communications systems as well as in military radar and electronic-warfare (EW) systems.

The model RX00103-005 digital receiver **(see figure)** is a single printed-circuit board (PCB) with RS-232C, VME, and HOTlink™ interfaces. The board features a pair of model TS83102 (10-b, 2-GSamples/s) analog-to-digital converters (ADCs) from Atmel Corp. (San Jose, CA), and as many as three Virtex-II field-programmable gate arrays (FPGAs). The ADCs work with a companion model TS81102 demultiplexer, which processes the 10-b ECL output signals from the ADCs onto an 80-b, single-ended bus running at one-eighth the sampling rate. The sampling delay and gain of the ADCs can be adjusted to support synchronizing and interleaving of multiple receiver boards for higher sam-



The RX00103-005 digital receiver processes a wide 3-GHz input bandwidth with a pair of high-speed ADCs that are backed by high-performance FPGAs.

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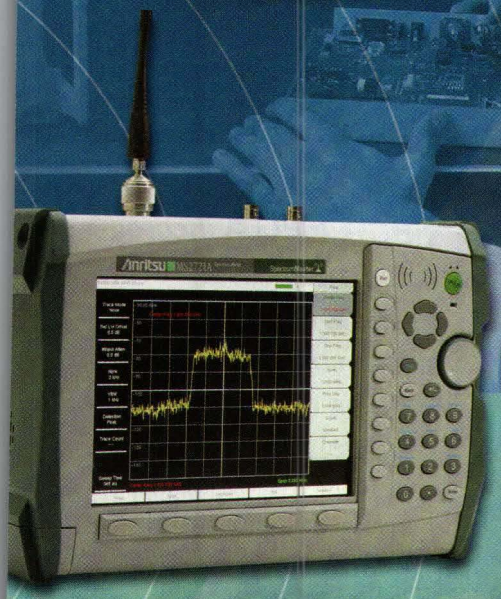
Benchtop Performance



INSIDE & OUT

Spectrum Master™ MS2721A

100 kHz to 7.1 GHz frequency range

-153 dBm typical displayed average noise level @ 1 GHz in 10 Hz RBW

-100 dBc/Hz SSB phase noise @ 10 kHz offset

Ethernet and USB 2.0 remote control

7.1 GHz

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pling rates.

The demultiplexer's output is connected to a Virtex-II FPGA using an 80-b single-ended data bus and a differential clock. Each FPGA incorporated into a given receiver has a CPU bus for direct communication with an on-board CPU module. The CPU provides the user interface, local control, and FPGA configuration for the receiver, as well as the RS-232C interface. The receiver includes 32 MB of flash memory to store FPGA configuration and other command information. Data collection and processing is controlled by means of a simple command set.

The receiver's high-speed Hotlink interface is implemented by means of a model CYP15G0101DXA high-speed-optical-transceiver link (HOTlink II™) from Cypress Semiconductor Corp. (San Jose, CA), which supports data rates of 0.2 to 1.5 GSamples/s. The transceiver contains all the logic needed for the serialize/deserialize (SERDES) function as well as clock recovery. One of the FPGAs serves as the system host to the transceiver, with data written/read between the transceiver and FPGA with the aid of a dual-port memory bank within the FPGA. The memory bank is also accessible by the CPU.

***Each FPGA** incorporated into a given receiver has a CPU bus for direct communication with an on-board CPU module.*

The RX00103-005 digital receiver can be powered by means of a 10-pin terminal block (for bench-top operation) or the VME backplane. Typical requirements are 700 mA at +3.3 VDC, 250 mA at +5 VDC, 1.8 A at –5 VDC, 300 mA at +1.5VDC, and 2.5 A at +2.5 VDC. The company offers both standard and custom signal-processing algorithms for the receiver.

The ISO 9001:2000 certified company also offers 38-GHz (37 to 40 GHz) transmitters and receivers for wideband line-of-sight applications. The transmitters and receivers, which operate with local oscillators (LOs) from 8 to 13 GHz and 2-GHz intermediate frequency (IF), are supplied with WR-28 waveguide RF inputs and SMA LO and IF connectors. The transmitter measures 7.1 × 3.0 × 1.0 in. while the receiver measures just 4.99 × 1.4 × 0.075 in. **LNX, 8B Industrial Way, Salem, NH 03079; (603) 898-6800, e-mail: sales@lnxcorp.com, Internet: www.lnxcorp.com.**

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4WAY	0.47-8.40
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MEMS Technology Arms 6-GHz Switch

This DC-to-6-GHz SPDT latching switch dispels all notions that MEMS technology is anything but reliable even under wide temperature ranges and severe vibration.

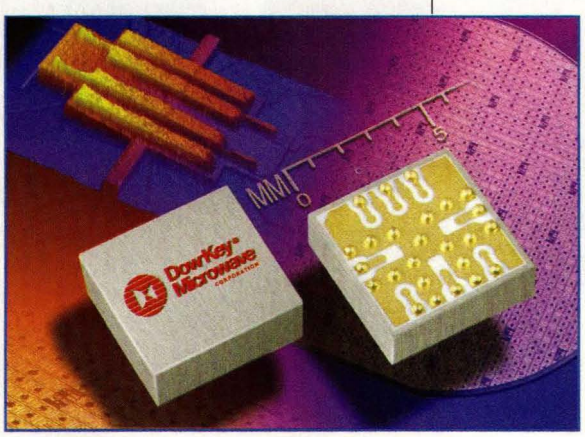
JACK BROWNE
Publisher/Editor

Signal routing in high-frequency systems requires reliable switches. For higher-power signals where speed is not an issue, designers often prefer the robust performance of electromagnetic (EM) switches. For lower-power signals where switching speed is important, diode or FET switches provide low-cost solutions. There is one other switch alternative, however, that blends the characteristics of EM and diode switches. The model M1C06-CDK2 switch from Dow-Key Microwave Corp. (Ventura, CA) incorporates microelectromechanical system (MEMS) technology to achieve 40-dB isolation from DC to 6 GHz with low power consumption and high reliability.

The model M1C06-CDK2 is a single-pole, double-throw (SPDT) bipolar latching MEMS switch that is rated for 100 million switching cycles. It employs gold contacts to maintain low-loss electrical connections even after millions of operations, and low-power magnetic actuation to shift the position of a short-travel cantilever from open to closed to effect latched switching. Bipolar voltage pulses of ±5 V set and reset the switch, which can handle input-power levels to 2 W CW. The linear device achieves a third-order intercept point of no less than +60 dBm and typically +65 dBm.

Although not on a par with the nanosecond switching speed of diode devices, the M1C06-CDK2 nonetheless achieves switching time of less than 200 µs and typically less than 50 µs. The insertion loss is 0.2 dB to 3 GHz and 0.5 dB to 6 GHz while the isolation is rated for 45 dB to 3 GHz and 40 dB to 6 GHz. The SPDT switch exhibits return loss of at least 20 dB to 3 GHz and at least 14.5 dB to 6 GHz.

In (quasi-hermetic) package form, the MEMS switch measures 5.88 × 5.88 × 2.78 mm; as a die, it is 1.96 × 1.64 mm. It typically consumes 140 mA current (170 mA maximum) at set/reset voltages of ±5 VDC, with no standby power (0 W) required. The switch is rated for operating temperatures from –40 to +85°C and is functionally tested under 10 g's vibration and 20 g's shock levels. **Dow-Key Microwave Corp., 4822 McGrath St., Ventura, CA 93003-7718; (805) 650-0260, FAX: (805) 650-1734, Internet: www.dowkey.com.**



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SPECIFICATIONS (@ 1GHz)

Model	Freq. (GHz)	In-Out Isol. dB(typ)	Ins. Loss dB(typ)	1dB Comp. dBm(typ)	Price $ea. (Qty. 10)
• M3SW-2-50DR	DC-4.5	60	0.7	25	4.95 *
■ *M3SWA-2-50DR*	*DC-4.5*	*65*	*0.7*	*25*	*4.95* *
					(Qty. 1-9)
• ZASW-2-50DR	DC-5	90	1.7	20	89.95
■ *ZASWA-2-50DR*	*DC-5*	*90*	*1.7*	*20*	*89.95*

Supply voltage +5V, -5V. TTL control.
Switching time 10nsec (typ).
• Reflective ■ *Absorptive*

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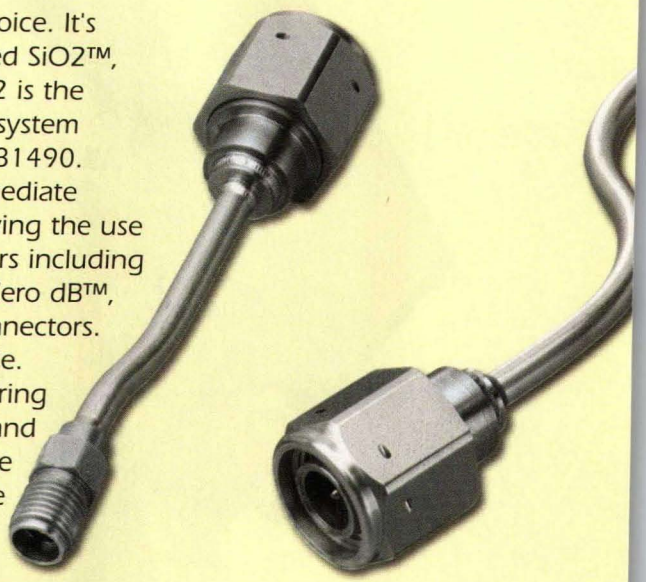

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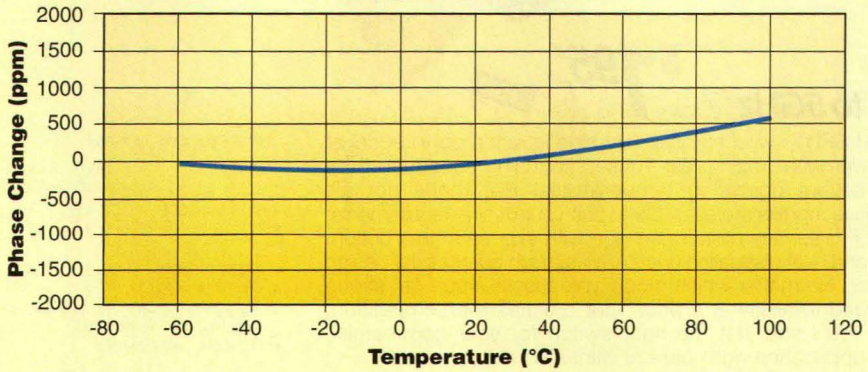

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MARKETING AND ADVERTISING STAFF

PUBLISHER/EDITOR
Jack Browne
(201) 845-2405
e-mail: jbrowne@penton.com

SALES ASSISTANT
Judy Kollarik
(201) 845-2427
e-mail: jkollarik@penton.com

DIRECT CONNECTION ADS CLASSIFIED ADVERTISING
Joanne Reppas
(201) 666-6698
e-mail: jrepfrangides@msn.com

CIRCULATION CUSTOMER SERVICE (LIVE)
Phone: (847) 763-9670
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SOUTHEAST, MID ATLANTIC
Paul Barkman
Global Sales Manager
Penton Media, Inc.
45 Eisenhower Dr., fifth floor
Paramus, NJ 07652
(908) 704-2460
FAX: (908) 704-2486
e-mail: pbarkman@penton.com

MIDWEST, SOUTHWEST, WESTCOAST
Michael Barkman
Account Executive
Penton Media, Inc.
45 Eisenhower Dr., fifth floor
Paramus, NJ 07652
(908) 832-6551
FAX: (908) 832-7052
e-mail: mbarkman@penton.com

NEW ENGLAND, CANADA
Tim Jemison
Business Development Manager
Penton Media, Inc.
45 Eisenhower Dr., fifth floor
Paramus, NJ 07652
(401) 608-6582
FAX: (401) 633-6201

GERMANY, AUSTRIA, SWITZERLAND
Friedrich K. Anacker
Managing Director
InterMedia Partners GmbH (IMP)
In der Fleute 46
D-42389 Wuppertal
Germany
Phone: 011-49-202-271-690
FAX: 011-49-202-271-6920

FRANCE
Emmanual Archambeaud
Defense & Communication
48 Bd Jean-Jaures,
92110 Clichy
France
Phone: 33-01-47-30-7180
FAX: 33-01-47-30-0189

TAIWAN, R.O.C.
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JAPAN
Hiro Morita
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Microwaves & RF (ISSN 0745-2993) is published monthly, except semi-monthly in December. Microwaves & RF is sent free to individuals actively engaged in high-frequency electronics engineering. In addition, paid subscriptions are available. Subscription rates for U.S. are $90 for 1 year ($115 in Canada, $145 for International). Published by Penton Media, Inc., The Penton Building, 1300 E. 9th St., Cleveland, OH 44114-1503. Periodicals Postage Paid at Cleveland, OH and at additional mailing offices.
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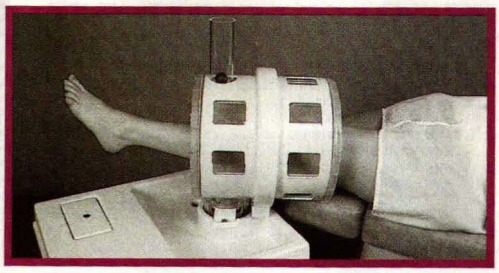

ALMOST 17 YEARS AGO, a special news report focused on microwave hyperthermia and how electromagnetic (EM) energy could be used to heat and destroy malignant cancer cells while leaving healthy tissues untouched.

next month

Microwaves & RF October Editorial Preview

Issue Theme: Emerging Technologies

News

The high-frequency industry has always relied on a healthy mix of technologies, both old and new, to reach the performance goals of its customers' devices, components, systems, and test equipment. In October, a Special Report will highlight some of the most significant emerging technologies, from high-power processes like silicon carbide and gallium nitride, to "carrierless" communications formats such as ultrawideband (UWB) technology. In addition, the news section will review 50 years of accomplishments at Merrimac Industries, and feature an exclusive interview with Peter Walters, president and CEO of iTerra Communications.

Design Features

October offers a cornucopia of technical articles that provide practical solutions for today's high-frequency engineering problems. For example, an author from Greenray Industries will detail the effects of acceleration forces on crystal-oscillator performance, while a contributor from Germany will describe how to create a voltage-controlled-oscillator (VCO) design capable of tuning 150 MHz around an 860-MHz center frequency. Additional design features in October will include Part 4 of the transistor amplifier design series by Dr. Joseph F. White, as well as a detailed look at a unique RF digital-to-analog-converter (DAC) design.

Product Technology

October's Product Technology will unveil the latest version of an industry-standard system-level computer-aided-engineering (CAE) suite of design tools, with enhancements that not only improve simulation accuracy but also make the powerful program easier to use. Additional Product Features will highlight BNC connectors for RF and microwave applications, a line of InGaP heterojunction-bipolar-transistor (HBT) gain blocks that can be used for drivers and preamplifiers from 100 to 2400 MHz, a 5.8-GHz transceiver design kit complete with fractional-N-synthesizer based transceiver, evaluation board, and software, a unique pricing program that helps reduce the expense of buying test equipment, and a high-performance switched-oscillator bank for space applications.

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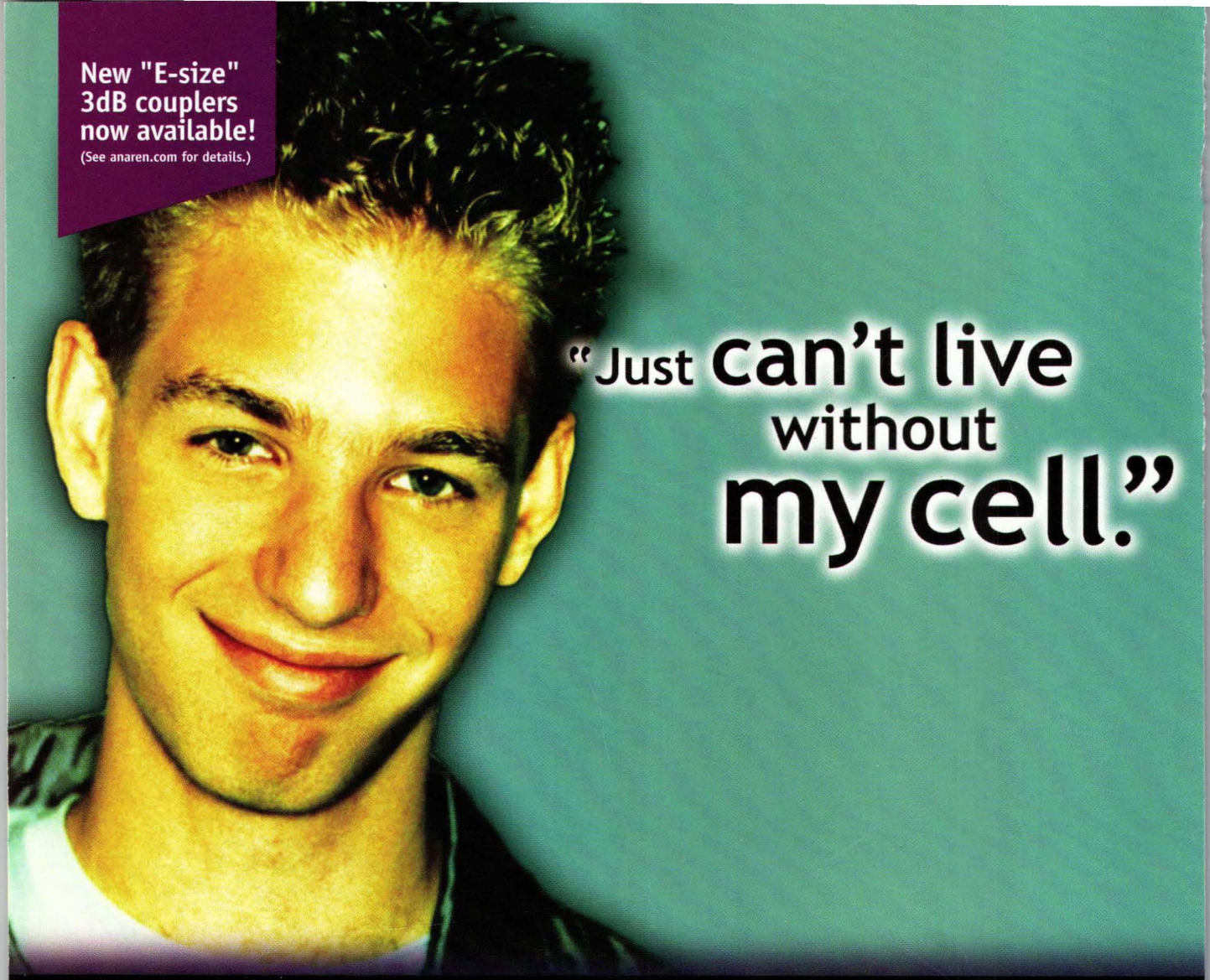

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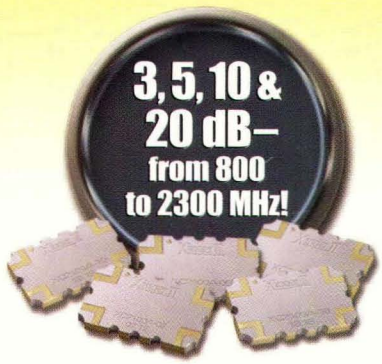

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